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Geological Sciences

OCCURRENCE AND DISTRIBUTION OF CONTAMINANTS IN BOTTOM SEDIMENT AND WATER OF THE BARRON RIVER CANAL, BIG CYPRESS NATIONAL PRESERVE, FLORIDA, OCTOBER 1998

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ABSTRACT: *Trace elements and organic contaminants in bottom-sediment samples collected from 10 sites on the Barron River Canal and from one site on the Turner River in October 1998 had patterns of distribution that indicated different sources. At some sites on the Barron River Canal, lead, copper, and zinc, normalized to aluminum, exceeded limits normally considered as background and may be enriched by human activities. Polynuclear aromatic hydrocarbons and* p-*cresol, normalized against organic carbon, had patterns of distribution that indicated local sources of input from a road or vehicular traffic or from an old creosote wood treatment facility. Phthalate esters and the trace elements arsenic, cadmium, and zinc were more widely distributed with the highest normalized concentrations occurring at the Turner River background site, probably due to the high percentage of fine sediment (74 % less than 63 micrometers) and high organic carbon concentration (42 %) at that site and the binding effect of organic carbon on trace elements and trace organic compounds. Low concentrations of pesticides or pesticide degradation products were detected in bottom sediment (DDD and DDE, each less than 3.5 μg/kg) and water (9 pesticides, each less than 0.06 μg/L), primarily in the northern reach of the Barron River Canal where agriculture is a likely source. Although a few contaminants approached criteria that would indicate adverse effects on aquatic life, none exceeded the criteria, but the potential synergistic effects of mixtures of contaminants found at most sites are not included in the criteria.*

BIG Cypress National Preserve (BICY) is a unique 295,000-hectare, water-dependent ecosystem (Fig. 1). As much as 90 % of the BICY is inundated

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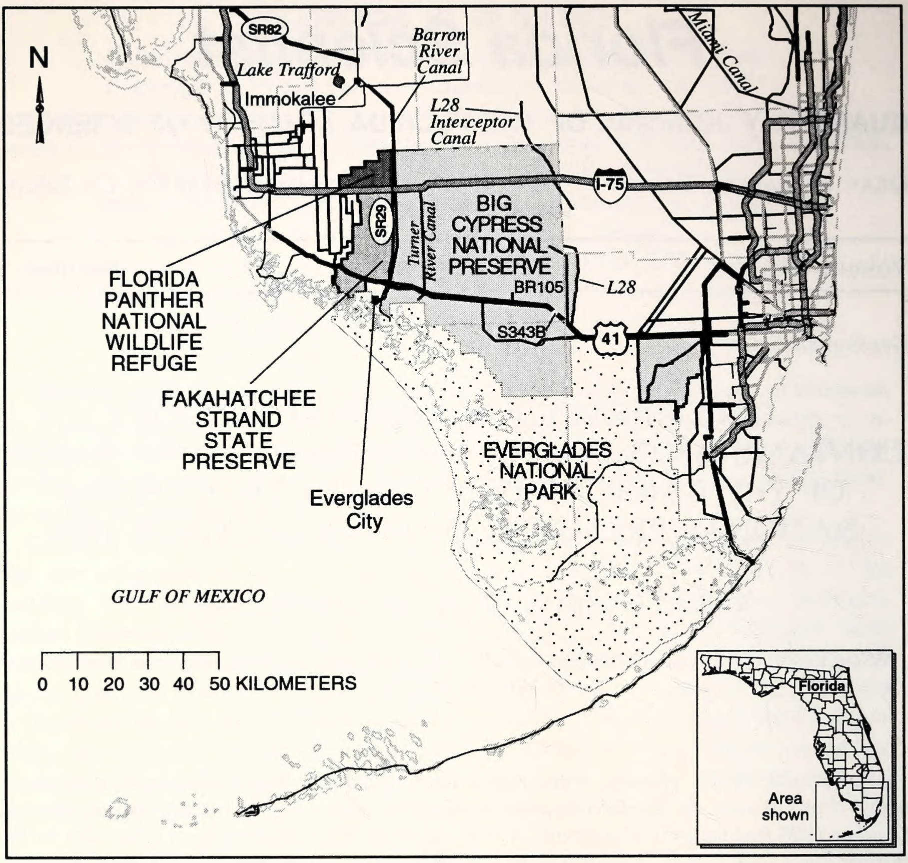

FIG. 1. The Big Cypress National Preserve and major canals including the Barron River Canal.

to depths ranging from several centimeters (cm) to more than 0.9 meter (m) during the wet season (May to October). During the dry season (November to April) water levels recede, reducing the area of inundation to approximately 10 %. The ecology of the BICY is finely tuned to the seasonal flow of non-polluted water and changes in seasonal flows or deterioration in water quality can adversely affect the BICY's sensitive habitat. As a result, it is important to identify local and regional impacts on water quality so these impacts can be lessened or averted.

BACKGROUND—With respect to hydrology, the BICY is one of the least altered ecosystems remaining in south Florida. Water quality in the BICY is typically good, as indicated by historical data collected by the U.S. Geological Survey (USGS) and by ongoing water-quality monitoring by the South Florida Water Management District (SFWMD) in cooperation with the BICY. However, along the western boundary of the BICY, the Barron

River Canal drains agricultural lands to the north, and also has other potential point sources of contamination along the canal. In addition, a number of pesticides have been reported in surface waters and bottom sediments in Collier County during 1989–92, including aldrin, BHC, chlordane, dieldrin, endosulfan sulfate, endosulfan I, endrin, and heptachlor (Shahane, 1994). As a result, the degradation of water and sediment quality is a cause of concern for the BICY.

Limited data indicate that water and sediment quality in parts of the Barron River Canal and vicinity are degraded. The C. J. Jones Lumber Company operated a sawmill at a location near the Barron River Canal from 1940 to 1956. From the early 1950s to 1956, it also operated a creosote wood treatment facility at the site (Law Engineering and Environmental Services, 1993). In 1990, the Florida Department of Environmental Regulation (FDER) investigated the site after a complaint was filed about water quality of residential wells in the Jerome area. The Collier Development Corporation entered into a Consent Agreement to assess the soil, sediment, surface water, and ground water at the site. In December 1990, the Collier Development Corporation excavated the former creosote wood treatment unit and the soils surrounding the unit. The excavated soils were thermally treated on site (Law Engineering and Environmental Services, 1993).

Contamination in the Barron River Canal area at the Jerome site was evaluated in April 1992–April 1993 (Law Engineering and Environmental Services, 1993). They analyzed samples for a group of semivolatile organic compounds (SVOCs) referred to as base/neutral extractables, and detected several SVOCs in bottom sediments in the nearby canal, and in ground water adjacent to and downgradient of the creosote wood treatment unit, but not in surface waters near the site. Contaminants found in bottom sediments included acenaphthene, anthracene, fluoranthene, fluorene, phenanthrene, and pyrene, and ranged in concentration from less than detection limits to more than 50,000 μg/kg (p. 36–37). A similar suite of base/neutral extractables were detected in ground waters near the creosote site, but also included naphthalene which was detected at concentrations up to 15,000 μg/L at one well. Two ground-water plumes of base/neutral extractables were defined in the vicinity of the former creosote wood treatment sites; a shallow plume at 9 m deep (below land surface) and a deeper plume at about 18 to 46 m deep (Law Engineering and Environmental Services, 1993, p. v).

Another potential source of contaminants exists along the Barron River Canal near Copeland, where a market, several abandoned buildings, mobile homes and other structures, a 3,800-liter underground storage tank, generators, transformers, abandoned vehicles, batteries, drums, other storage tanks, and trash are located. The underground storage tank was used for unleaded gasoline sales and contamination has been reported but no cleanup had begun by 1998 (Law Engineering and Environmental Services, 1998).

According to a report by the Collier County Environmental Services

Division (1994, p. 48) that summarized sediment quality throughout the county's inland canal system from 1989 to 1991, the Barron River Canal had the highest bottom-sediment concentration of 99 μg/kg of δ-BHC reported for the State of Florida. δ-BHC is a degradation product of lindane (γ-BHC). This high value was reported at a site where County Road (CR) 858 crosses the canal (Grabe, 1996).

Grabe (1996) summarized sediment-contaminant data collected in Collier County, which includes the BICY and the Barron River Canal. He reported that trace elements were enriched in some canals, pesticides were detected in more than 40 % of the samples collected, and that polynuclear aromatic hydrocarbons (PAHs) occurred in very high concentrations in at least one canal in the county. In addition, Mattraw (1973) indicated that certain trace elements were transported from agricultural lands north of BICY to estuaries of the 10,000 Islands. Because the Barron River Canal drains farm lands north of the BICY, it is reasonable to assume that the canal may transport contaminants to the BICY, Everglades National Park, and the 10,000 Islands. The extent of the contaminants contained in the Barron River Canal, however, is not well defined, but this information is needed to evaluate potential effects on the Preserve and downstream areas.

PURPOSE AND SCOPE—The objective of this article is to describe the occurrence and distribution of a wide range of potential trace-elemental and organic contaminants in the bottom sediments of the Barron River Canal and to compare the occurrence and distribution with antecedent data collected in the vicinity of the study area. Bottom sediments were analyzed for 96 organic compounds or groups of compounds including pesticides, PAHs, phthalate esters, and polychlorinated biphenyls (PCBs). Pesticide contaminants were also evaluated in the canal water during the sampling period, October 26–29, 1998, as part of a National Water-Quality Assessment study. The Barron River Canal extends south from near Immokalee to Everglades City (Fig. 1), a distance of about 64 kilometers (km). The northern 19 km of the canal within our study area drains urban-residential areas near Immokalee and agricultural lands; the remaining southern part of the canal drains through preserves, including the BICY to the east and the Florida Panther National Wildlife Refuge and Fakahatchee Strand State Preserve to the west. The Turner River background (control) site is in the BICY and is 8 km east of the Barron River Canal. The Turner River receives water from the Turner River Canal that has some human influences such as a lightly-traveled, unpaved road adjacent to it. The drainage basin of the Turner River Canal is sparsely populated and extends north of I-75.

METHODS—Bottom-sediment samples were collected at 11 sites (Fig. 2; Table 1) in October 1998 by using a stainless steel Ekman dredge. Barron River Canal is cut through limestone with little soil at the surface, and bottom sediments in some places are composed mainly of limestone debris, sand, and organic detritus. We attempted to locate and sample depositional

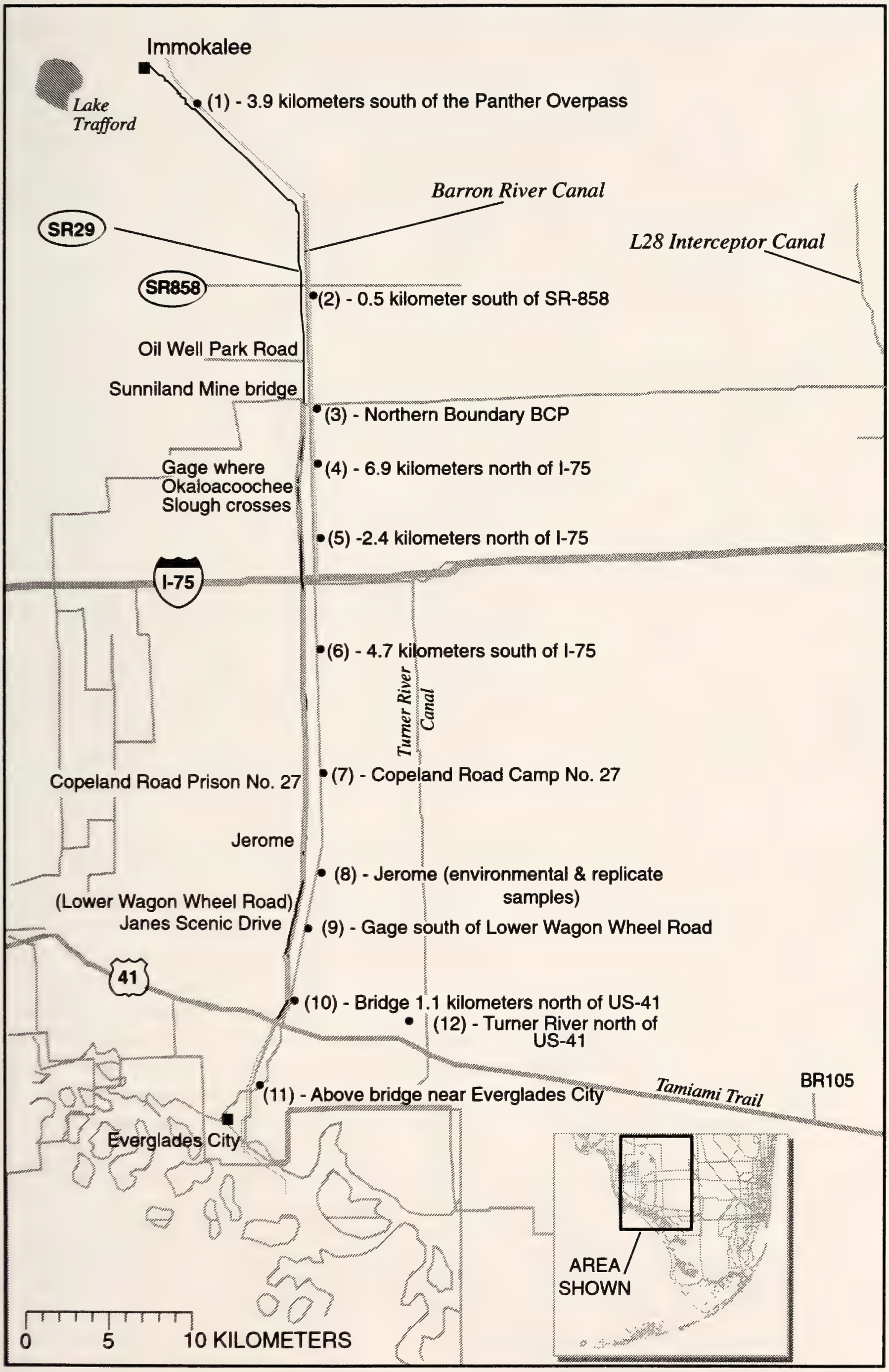
Immokalee
Lake Trafford
(1) - 3.9 kilometers south of the Panther Overpass
Barron River Canal
SR29
L28 Interceptor Canal
SR858
(2) - 0.5 kilometer south of SR-858
Oil Well Park Road
Sunniland Mine bridge
(3) - Northern Boundary BCP
Gage where Okaloacoochee Slough crosses
(4) - 6.9 kilometers north of I-75
(5) -2.4 kilometers north of I-75
I-75
(6) - 4.7 kilometers south of I-75
Turner River Canal
Copeland Road Prison No. 27
(7) - Copeland Road Camp No. 27
Jerome
(8) - Jerome (environmental & replicate samples)
(Lower Wagon Wheel Road) Janes Scenic Drive
(9) - Gage south of Lower Wagon Wheel Road
41
(10) - Bridge 1.1 kilometers north of US-41
(12) - Turner River north of US-41
(11) - Above bridge near Everglades City
Tamiami Trail
BR105
Everglades City
AREA SHOWN
0
5
10 KILOMETERS

FIG. 2. Location of sampling sites along the Barron River Canal and on the Turner River.

TABLE 1. Sampling sites: October 1998.

Map number	Station identification	Site names	Distance south of Panther Overpass, kilometers[b]	Type of samples collected
1	262247081215500	BRC[a] 3.9 kilometers south of Panther Overpass	3.9	BSed[c], SW[d]
2	261812081203400	BRC 0.5 kilometer south of CR-858	13.8	BSed
3	261524081202900	BRC at the northern boundary of Big Cypress Preserve	18.5	BSed
4	261306081204000	BRC 6.9 kilometers north of I-75	22.8	SW
5	261036081204400	BRC 2.4 kilometers north of I-75	27.4	BSed
6	260650081204100	BRC 4.7 kilometers south of I-75	34.4	BSed
7	260231081203900	BRC at Copeland Road Camp No. 27	42.8	BSed, SW
8	255937081205000	BRC at Jerome	47.8	BSed
9	255740081211100	BRC gage below Wagon Wheel Road	51.5	BSed
10	255511081213000	BRC 1.1 kilometers north of US-41	56.0	BSed, SW
11	255218081225700	BRC near Everglades City bridge	61.8	BSed
12	255353081155400	Turner River north of US-41	not applicable	BSed

[a] Barron River Canal.
[b] Distances are from odometer readings and are only approximate.
[c] Bed-sediment sample collected.
[d] Surface-water sample collected.

areas containing mainly fine organic sediment. At each sampling site, bottom sediments were composited from 5 or more surface (top 2–3 cm) sediment samples to obtain a representative sample. Bottom sediment was taken from the top of the dredge, avoiding any contact with sides of the dredge. Samples were passed through a 2-mm sieve and shipped to the USGS National Water Quality Laboratory (NWQL) for analyses. All bottom-sediment concentrations are reported on a dry-weight basis. The grab samples were composited in pre-cleaned glass or Teflon bowls. The dredge, stainless steel sieve, bowls, and processing tools for organic analyses were cleaned with Liquinox, distilled water, and methanol after sampling each site. The bowls, sieves, and tools for processing trace elements were cleaned with Liquinox, deionized water, 5 % HCl solution, and deionized water again. A new, clean rope was used for the dredge at each site. Samples were processed immediately after collection, preserved appropriately, and shipped to the NWQL. Quality control procedures were followed. One concurrent replicate sample was collected from the Jerome site on Barron River Canal and analyzed for the same constituents as the environmental samples.

Filtered water samples were also collected at four sites on the Barron River Canal during October 26–29, 1998, and analyzed for a suite of 83 pesticides or pesticide degradation products. The water samples were collected by using a depth integrated procedure at several points across the width of the canal, processed according to USGS parts-per-billion protocols (Shelton, 1994), and shipped to the NWQL for analysis.

For the purpose of interpretation, concentrations of trace elements in bottom sediments were plotted against or divided by aluminum concentrations to normalize their concentrations. The normalization reduces the variation in concentration due to the variation of the clay concentration from one site to the next and sometimes allows natural background concentrations to be distinguished from concentrations enriched by human activities (Schropp and Windom, 1988). The trace element-to-aluminum plots show the 95 % confidence intervals derived from "clean" Florida coastal bed sediment data of Schropp and Windom (1988). Data that fall within the 95 % confidence intervals are considered as "background." Data above the 95 % prediction limits may indicate trace element enrichment above natural background concentrations.

Concentrations of trace organic compounds were normalized against organic carbon concentrations to reduce the influence of bulk sediment composition on spatial patterns. To normalize the data, the concentrations of each organic compound were divided by the concentration of organic carbon. The original reporting units are μg/kg for SVOCs and g/kg for organic carbon; consequently, the ratios from the reported concentrations are the same as if the concentrations were converted to the same units and multiplied by a unit conversion factor of 1 million. If the ratios for one compound were much larger than for the other compounds, a smaller multiplier was used in graphs to show more detail for the other compounds. Hydrophobic organic compounds have an affinity for organic matter and, consequently, bottom sediments that are rich in organic carbon compounds adsorb more SVOCs than do bottom sediments that are mainly composed of inorganic matter. The normalization procedure enhances the ability to distinguish local inputs of SVOCs from variations that are simply due to variations in the bulk concentration of organic matter in the sediment samples.

Analytical data below the usual method reporting limits were used in some cases in the interpretation and presentation of data. If the presence of an analyte is verified by spectra and is below the method reporting limits, the concentration is reported as an estimated value. The use of analytical data below the usual method reporting limits was justified by Pritt (1994) in a U.S. Geological Survey Technical Memorandum.

Available aquatic-life criteria for bottom sediment and water were used to evaluate potential adverse biological effects of analytes detected during this study. Data from the Barron River Canal and Turner River sites were compared with aquatic-life criteria developed by Environment Canada (1999), U.S. Environmental Protection Agency (USEPA, 1996), National Oceanic and Atmospheric Administration (Long and Morgan, 1990; Long et al, 1995), and Florida Department of Environmental Protection (FDEP, 1994). Gilliom and coworkers (1998) summarized a number of the aquatic-life criteria from the above sources. Where available, we used the Canadian probable effects level (Environment Canada, 1999) for evaluations of water and sediment concentrations. For a few substances, other criteria were used in the absence of Canadian criteria. Aquatic-life criteria are usually based on research done on individual chemicals or classes of compounds and do not account for the synergistic effect of mixtures of chemicals that occur in the environment (USGS, 1999).

The criteria for trace elements in bottom sediments were developed by using analyses of bottom sediments that were partially digested with acid in an attempt to measure bioavailability. Trace element analyses were determined by a relatively complete digestion commonly used for geochemical investigations. The essentially complete digestion tends to yield higher concentrations than partial digestion and might, in some cases, make contamination appear more severe.

RESULTS AND DISCUSSION—Variability in the analytical results is inferred from a comparison of data for the environmental and concurrent replicate samples collected at the Jerome site on the Barron River Canal. For the replicate sample, concentrations (including estimated values below the method reporting level) differed by 0 to 37 % for trace elements and by 2 to 91 % for the SVOCs. Part of this variability is due to actual differences in the composition of the samples collected (sampling error) and part is due to normal errors associated with extraction or digestion procedures and subsequent chemical analyses. Differences between the environmental and rep-

TABLE 2. Selected trace-element and organic carbon concentrations in bottom sediments from the Barron River Canal and Turner River and aquatic-life criteria: October 1998.

Element, units	Laboratory minimum reporting level	[a]Observed range in Barron River Canal and Turner River	[b]Canadian probable effect levels for freshwater sediment	[c]Effects-range median	[d]Average crustal abundance
Arsenic, [e]μg/g	0.1	1–14	17.0	85	1.8
Cadmium, μg/g	0.1	<0.1–0.6	3.5	9	0.15
Chromium, μg/g	1	6–77	90.0	145	102
Copper, μg/g	1	2–82	197	390	60
Mercury, μg/g	0.02	0.02–0.29	0.486	1.3	0.085
Lead, μg/g	4	3–40	91.3	110	14
Nickel, μg/g	2	<2–16	[f]—	50	84
Selenium, μg/g	0.1	<0.1–1.4	—	—	0.05
Zinc, μg/g	4	5–180	315	270	70
Aluminum, %	0.005	0.15–2.4	—	—	—
Organic carbon, %	0.02	0.75–42	—	—	—

[a] Concentrations in dry weight.
[b] Environment Canada, 1999.
[c] Long and Morgan, 1990.
[d] Rice, 1999.
[e] Microgram per gram.
[f] Not available.

licate concentrations at Jerome were generally small compared with the observed ranges along the canal.

Trace elements—The range in concentrations of selected trace and major elements at the 10 Barron River Canal sites and one Turner River site is given in Table 2. Concentrations of trace elements were less than bottom-sediment probable effect levels (Environment Canada, 1999) and the aquatic-life criteria (effects-range median, ER-M) developed by Long and Morgan (1990) for the National Oceanic and Atmospheric Administration's (NOAA) Status and Trends Program. However, concentrations of chromium, arsenic, and mercury reached 86, 82, and 60 % of the probable effect levels, respectively, in some samples.

Concentration of seven trace-elements in bottom sediment are plotted against aluminum concentration (Fig. 3). The 95 % confidence limits for clean Florida estuarine bottom sediments that were determined by Schropp and Windom (1988) are included on the figure for each trace element to help evaluate possible enrichment.

Most of the naturally occurring trace elements are incorporated in the aluminosilicate structure of clays and other weathered materials and are not readily available to aquatic biota. Trace elements from anthropogenic sources tend to be adsorbed on sediment and are usually more available to the aquatic biota. Thus, elements with element-to-aluminum ratios significantly above the upper 95 % confidence limits have the potential to produce adverse

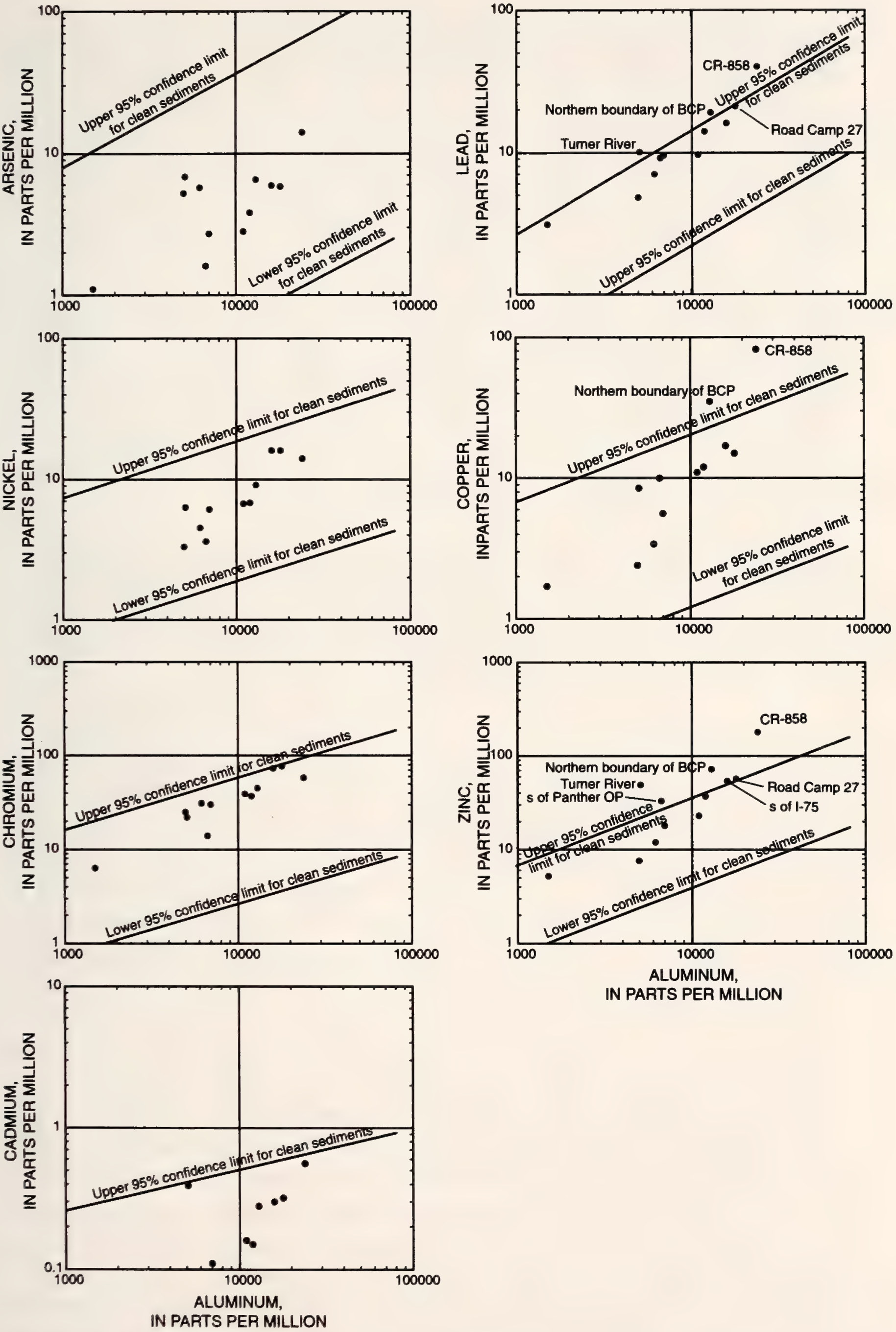

FIG. 3. Concentrations of trace elements plotted against concentrations of aluminum in bottom sediments from the Barron River Canal and Turner River, October 1998. The 95 percent confidence intervals are for clean Florida estuarine sediments from Schropp and Windom (1988).

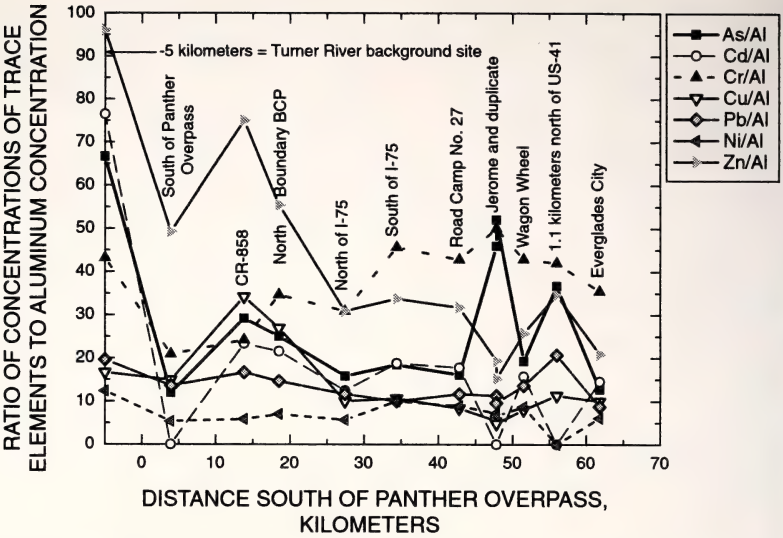

FIG. 4. Ratios of concentrations of trace elements to concentrations of aluminum in bottom sediments along the Barron River Canal and from the Turner River, October 1998. Most trace element to aluminum ratios are multiplied by 10,000 except for cadmium to aluminum and arsenic to aluminum ratios that are multipled by 1,000,000 and 50,000, respectively, to show more detail. Ratios of 0 are for less-than values.

biological effects. Ratios for arsenic and nickel were within the 95 % range indicative of natural background levels for these elements. Some of the chromium and two of the cadmium ratios were near the upper 95 % confidence levels for natural bottom sediments. Lead, copper, and zinc had some ratios above the upper 95 % confidence levels and suggest that human activities may have enriched these elements above natural levels at some sites. Possible anthropogenic sources of trace element enrichment in south Florida canals include biomass burning, runoff from manure and fertilizers, release from wear of automobile parts, irrigation return flow, and municipal waste (Rice, 1999).

The distribution of trace element-to-aluminum ratios along the Barron River canal and at the Turner River site is shown (Fig. 4). The highest ratios for arsenic, cadmium, and zinc were at the Turner River background site, possibly due to the high organic carbon concentration (42 %) and the binding effect that organic carbon can have on metals. Cadmium was strongly correlated with aluminum ($p<0.0001$) and organic carbon ($p<0.0001$). Zinc and arsenic were strongly correlated with aluminum ($p<0.0009$ and $p<0.008$, respectively) and weakly correlated to organic carbon ($p<0.17$ and $p<0.10$, respectively). Chromium was strongly correlated with aluminum ($p<0.0006$) but was not correlated with organic carbon ($p<0.89$). The high concentration of organic carbon and the correlation of cadmium, zinc, and arsenic with organic carbon concentrations partially explains the high trace element to

TABLE 3. Selected concentrations of semivolatile organic compounds in bottom sediments from the Barron River Canal and the Turner River and aquatic-life criteria: October 1998.

Classes and compounds	[a]Concentration range	[b]Canadian probable effect levels	[c]Aquatic-life criteria
[e]PAHs			
Acenaphthene	[d]20E–50E	88.9	1,300
Acenaphthylene	3E–50E	128	640
Anthracene	5E–80E	245	1,100
Benzo(a)anthracene	3E–60E	385	693
Benzo(a)pyrene	20E–200	782	782
Chrysene	10E–260	862	862
Dibenzo(a,h)anthracene	10E–50E	135	260
Fluoranthene	20E–460	2,355	6,200
Fluorene	4E–29E	144	—
Naphthalene	10E–80	391	470
Phenanthrene	3E–130	515	1,800
Pyrene	30E–390	875	1,398
Phthalate esters			
Butylbenzyl phthalate	30E–7700	[g]—	11,000
Diethyl phthalate	10E–30E	—	630
Di-n-butyl phthalate	10E–170E	—	11,000
Bis(2-ethylhexyl)phthalate	40E–2500	—	2,650
[f]PCBs			
Total PCBs	<250	277	189
Chlorobenzenes			
1,2-dichlorobenzene	<200	—	340
1,4-dichlorobenzene	<200	—	350
1,2,4-trichlorobenzene	<200	—	9,200

[a] Concentrations in micrograms per kilogram of dry weight.
[b] Environment Canada, 1999.
[c] Gilliom et al., 1998.
[d] E indicates an estimated concentration.
[e] PAHs, polynuclear aromatic hydrocarbons.
[f] PCBs, polychlorinated biphenyls.
[g] Not available.

aluminum ratios for these elements at the Turner River background site. The highest ratios for chromium and the second highest ratio for arsenic were at the Jerome site on the Barron River Canal. Arsenic and copper had small peaks in their ratios at the Barron River CR-858 site. The CR-858 and Jerome sites have a history of contamination that is the likely cause of the local peaks in some trace-element ratios.

Polynuclear aromatic hydrocarbons, phthalate esters, and PCBs—The range of concentrations for selected SVOCs, including PAHs, phthalate esters, and PCBs, from the Barron River Canal and Turner River sites is given in Table 3. Concentrations were below aquatic-life criteria. However, bis(2-ethylhexyl) phthalate (south of I-75) and butylbenzyl phthalate (Turner River) approached within 94 and 70 %, respectively, of the aquatic-life criteria

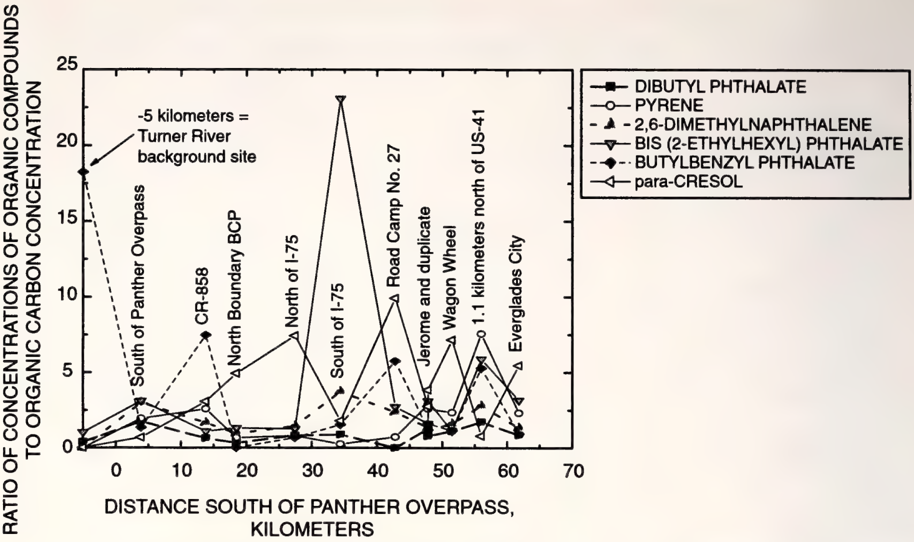

FIG. 5. Ratios of the concentrations of selected trace organic compounds to concentrations of organic carbon in bottom sediments along the Barron River Canal and the Turner River, October 1998. Ratios are multiplied by 1,000,000 except for *p*-cresol that is mutiplied by 100,000 to show more detail. Ratios of 0 are for less-than values.

summarized by Gilliom and coworkers (1998). Mixtures of SVOCs and other contaminants found at some sites could behave synergistically to cause adverse biological effects that are not indicated by criteria developed for each individual contaminant (USGS, 1999).

The six most frequently-detected SVOCs, normalized to organic carbon, are plotted against distance along the Barron River Canal to assess potential local sources (Fig. 5). The ratio for bis(2-ethylhexyl)phthalate peaked at the site just south of I-75, indicating a potential source for this widely-used plasticizer. Other patterns in the ratios of SVOCs are difficult to interpret as discussed below. The ratio for bis(2-ethylhexyl)phthalate also varied inversely with the ratio for *p*-cresol, a disinfectant, fungicide, and insecticide. Another plasticizer, butylbenzyl phthalate, varied in the canal between nearby sites with similar concentrations of organic carbon, and the highest ratio was at the Turner River background site (also shown on Fig. 5 at −5 km). Normalizing trace organics to organic carbon helps to minimize some variations in the effects of sediment composition, but it does not compensate for differences in the size of the organic particles, the chemical composition of the organic matter, or the residence time of sediment at a site, and all of these can have an effect on retention of contaminants in addition to any local inputs of contamination. In addition, approximately two thirds of the concentrations used to compute the ratios were near or below the method reporting levels; therefore, precision is low and may contribute to variability (Fig. 5).

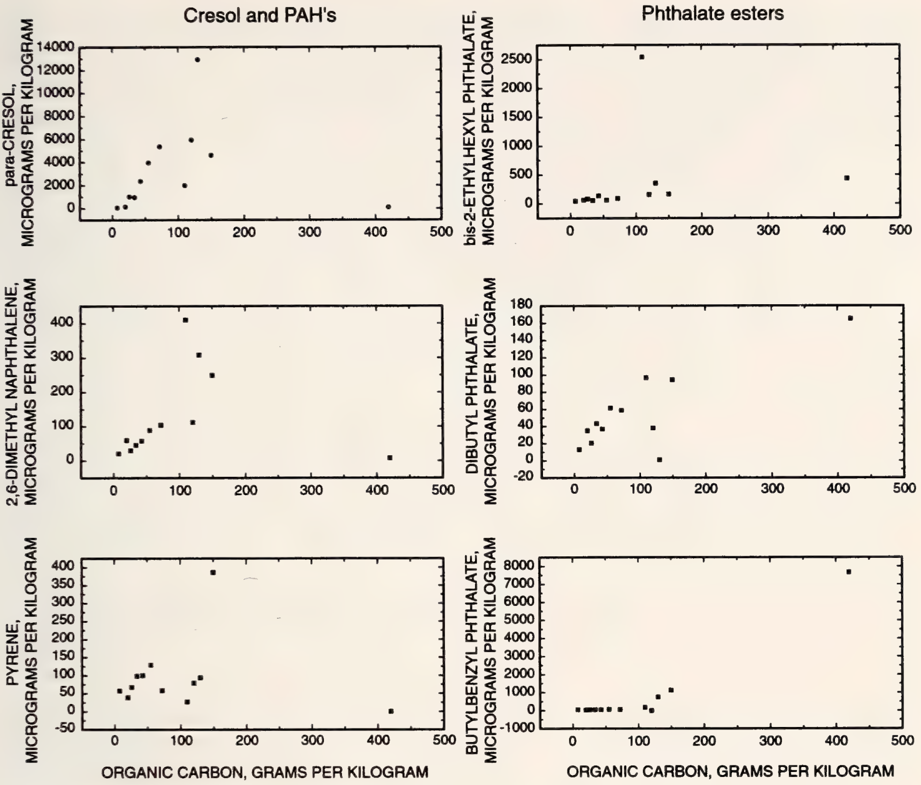

FIG. 6. Concentrations of selected semivolatile organic compounds plotted against concentrations of organic carbon in bottom sediments from the Barron River Canal and the Turner River, October 1998.

When concentrations of SVOCs were plotted against the concentration of organic carbon in bottom sediment, two groups of compounds emerge with different distributional patterns (Fig. 6). In both groups of compounds, the concentration of SVOCs generally increased with increasing organic carbon content. However, concentrations of the PAH and cresol group (pyrene, 2,6-dimethylnaphthalene, and *p*-cresol) at the Turner River background site fall well below the trend line for the Barron River Canal samples, whereas concentrations of the esters [bis(2-ethylhexyl)phthalate, di-n-butyl phthalate, and butylbenzyl phthalate] at the Turner River are in line with the general trend in the Barron River Canal samples. Although there were fewer reportable values for fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, benzo[k]fluoranthene, benzo[g,h,i]perylene, phenanthrene, phenol, acenaphthylene, anthracene, benzo[a]anthracene, chrysene, and benzo[b]fluoranthene; plots (not shown) of these compounds against organic carbon concentrations were similar to those for pyrene, 2,6-dimethylnaphthalene, and *p*-cresol shown in Fig. 6. Except for the relatively high (2,500 μg/kg) concentration of bis(2-ethylhexyl)phthalate in the

Barron River Canal south of I-75, the highest concentration of the phthalate esters occurred at the Turner River background site that had the highest percentage of fine sediment (74 % less than 63 micrometers) and highest concentration (42 %) of organic carbon. Local inputs of contaminants are probably minor at this background site.

We interpret the different distributional patterns and behavior between the phthalate esters compared to the PAHs and *p*-cresol to mean that the phthalate esters have a general and widespread source such as atmospheric precipitation or atmospheric transport of phthalate ester vapors and that the PAHs and *p*-cresol have a local source that does not affect the Turner River, such as State Road 29 (SR-29) that is adjacent to the Barron River Canal along its entire length. Possible source of the PAHs and *p*-cresol associated with SR-29 could be from leakage of vehicle fluids, vehicle exhaust, or leaching of the roadbed materials such as asphalt. Kriech (1990) suggests that leaching of asphalt road surfaces are not significant sources of trace elements and SVOCs, but that crankcase oil and tire wear material from vehicles are the potential sources of some SVOCs such as naphthalene and phenanthrene.

The association of high PAH concentrations with roadways or traffic is indicated from a bottom-sediment sample collected 23 km east of the Barron River Canal at the heavily traveled Tamiami Trail (US-41) Bridge 105 site in August 1996. This site had the highest concentrations of pyrene (640 μg/kg), benzo(a)pyrene (690 μg/kg), benzo(k)fluorene (580 μg/kg), benz(a)anthracene (490 μg/kg), and chrysene (540 μg/kg) of 7 southern Florida National Water-Quality Assessment sites (R.L. Miller, U.S. Geological Survey, unpublished data) and of the Turner River and 10 Barron River Canal sites.

The high concentrations of PAH contaminants (up to 50,000 μg/kg) reported by Law Engineering and Environmental Services (1993) for bottom sediments in the Jerome area of the Barron River Canal were not evident in our Jerome bottom sediment samples or in samples downstream of Jerome. The high values reported by Law Engineering and Environmental Services were from samples collected in the Barron River Canal just upstream of the Jerome borrow pit and were confined to a length of less than 300 m of the canal. Our Jerome samples were collected in the canal just downstream of the borrow pit mouth. Although our research did not detect the high PAH concentrations reported by Law Engineering and Environmental Services, we did see higher values for normalized PAH concentrations (for the 6 compounds measured at high concentrations by Law Engineering and Environmental Services) at Jerome and downstream of Jerome than upstream (Fig. 7). In addition to the difference in sampling location, the lower concentrations in our Jerome samples compared with those of Law Engineering and Environmental Services may result from the downstream migration of contaminants, dilution by mixing of sediments, and degradation of these compounds over time. Fluoranthene and pyrene had the highest ratios to organic carbon about 8 km downstream of Jerome perhaps due to down-

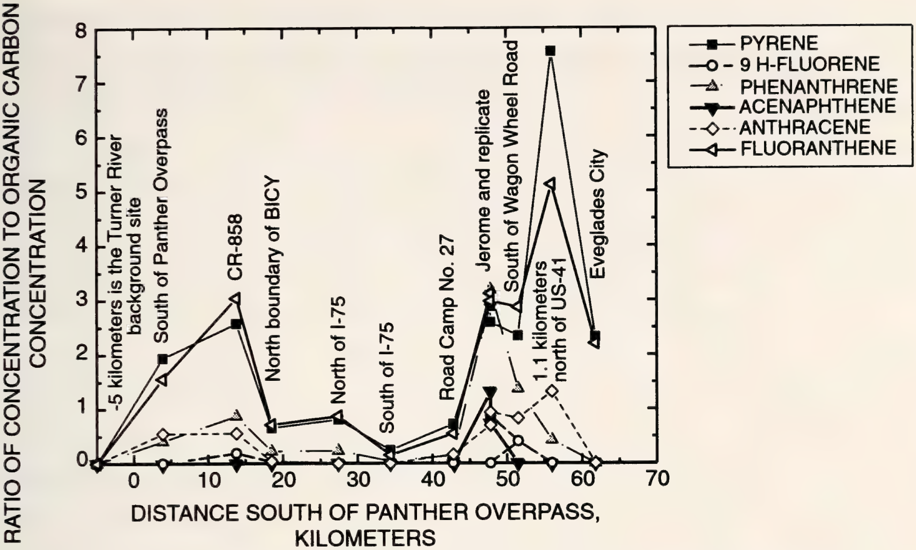

FIG. 7. Ratios of concentrations of selected polynuclear aromatic hydrocarbons to concentrations of organic carbon in bottom sediments along the Barron River Canal and the Turner River, October 1998.

stream migration. Smaller peaks for these and other PAHs occurred at Jerome and at CR-858 (Fig. 7).

Pesticides in bottom sediment and water—The range of concentrations for selected organochlorine pesticides in bed sediment from the Barron River Canal and Turner River sites, along with criteria for aquatic life, are given (Table 4). No pesticides were detected in sediment from the Barron River

TABLE 4. Concentrations of selected organochlorine pesticides in bottom sediments from the Barron River Canal and the Turner River and aquatic-life criteria: October 1998.

Compound	[a]Concentration range	[b]Canadian probable effect levels	[c]Aquatic-life criteria
Total chlordane	<5	8.87	6
p,p'-DDD + *o,p'*-DDD	<1–1.5	8.51	[d]—
p,p' DDE + *o,p'* DDE	<1–3.4	6.75	—
p,p'-DDE	1–3	—	15
Total DDT	<10	4.77	46.1
Dieldrin	<5	6.67	110
Endrin	<10	62.4	42
γ-HCH (lindane)	<5	1.38	1.38
Heptachlor epoxide	<5	2.74	—

[a] Concentrations are in micrograms per kilogram of dry weight.
[b] Canadian probable effect levels from Environment Canada, 1999.
[c] Aquatic-life criteria summarized by Gilliom et al., 1998.
[d] Not available.

TABLE 5. Concentrations of pesticides detected in surface water: October 1998 and June 1997.

	3.9 kilometers south of Panther Overpass[a]	6.9 kilometers north of I-75[a]	Copeland Road Camp No. 27[a]	1.1 kilometers north of US-41[a]	1.1 kilometers north of US-41[b]	[c]Canadian fresh-water guide-lines for protec tion of aquatic life	[d]Aqua-tic-life criteria
Atrazine	[e,f]0.01E	0.01	0.007E	0.006E	0.003E	1.8	2
Carbaryl	0.007E	0.009E	0.008E	0.007E	<0.003	0.20	[g]—
2,4-D	<0.15	<0.15	<0.15	<0.15	0.15	—	4
Desethylatrazine	0.006E	0.003E	0.003E	<0.002	<0.002	—	—
Diuron	0.05	<0.02	<0.02	<0.02	<0.02	—	—
Metolachlor	0.005E	0.005	<0.004	<0.002	<0.002	7.8	8
Metribuzin	<0.004	0.007	<0.004	<0.004	<0.004	1.0	1
Norflurazon	0.02E	<0.02	<0.02	<0.02	<0.02	—	—
Propanil	<0.004	0.004E	<0.004	<0.004	<0.004	—	—
Simazine	<0.04	0.005	<0.01	<0.01	0.003E	10	10

[a] Sampled October 1998.
[b] Sampled June 1997.
[c] Canadian freshwater guidelines for protection of aquatic life from Environment Canada, 1999.
[d] Aquatic-life criteria for surface water summarized by Gilliom et al., 1998.
[e] Concentrations in micrograms per liter.
[f] E indicates an estimated concentration.
[g] Not available.

Canal and Turner River sites except for 2 concentrations of *p,p′*-DDE at the two most northern canal sites (1.1 μg/kg south of the Panther Overpass and 3.4 μg/kg south of CR-858), and one concentration of 1.5 μg/kg of *p,p′*-DDD south of Wagon Wheel Road. Both of these compounds are degradation products of DDT, but DDD is also an insecticide. None of the detected pesticides exceeded aquatic-life criteria.

Although Grabe (1996) found 99 ppb (μg/kg) of α-BHC (a degradation product of lindane which is also called γ-BHC) in the Barron River Canal near CR-858, we did not detect (at detection limits of 1–4 μg/kg) lindane or the α and β isomers of BHC in any of our Barron River Canal samples collected in October 1998. Pesticides in the bottom sediments of the Barron River Canal were less frequently detected and occurred in lower concentrations than those measured at some other sites is south Florida in 1995–96 as part of the National Water-Quality Assessment Program. Haag and coworkers (1998) show site locations of these unpublished data.

Nine pesticide compounds were detected (18 detections including estimated values) in water samples collected October 26–29, 1998, at four sites along the Barron River Canal (Table 5). Thirteen of the 18 detections were at the two northern sites and in most cases pesticide concentrations were highest at the two northern sites. The northern sites are within the citrus and vegetable growing areas near Immokalee. Samples for pesticides in water were also previously collected three times at the Barron River Canal site 1.1 km north of US-41 (Miller et al, 1999), and the following pesticides were detected: atrazine (0.004 μg/L) and propanil (0.006 μg/L) in August 1996; atrazine (0.003 μg/L), simazine (0.003 μg/L), and 2,4-D (0.15 μg/L) in June 1997. In August 1997, no dissolved pesticides were detected at that site. Miller and others (1999) also sampled two BICY sites along the Tamiami Trail that were 23 and 56 km east of the Barron River Canal and detected atrazine, desethylatrazine, tebuthiuron, and azinphos-methyl.

CONCLUSIONS—Some of the SVOCs and trace elements sampled in October 1998 show patterns of distribution that relate to local point or nonpoint sources, whereas others appear to have more widespread sources such as the atmospheric transport of phthalate esters or the natural distribution of trace elements. Bottom-sediment characteristics such as organic carbon or clay content also influence the observed concentrations of many organic compounds or trace elements, respectively; but we used the normalizing techniques to minimize that influence. However, other sediment characteristics, such as particle size, composition, and residence time may also affect concentrations of trace substances in bottom sediments.

Some concentrations of PAHs normalized to organic carbon concentrations show peak concentrations along the Barron River canal at CR-858, at Jerome, and at sites downstream of Jerome. While the roadway and associated vehicular activity are probably a general source of PAHs in the Barron River Canal, the peaks in the normalized concentrations are probably related to contamination near CR-858 and the former creosote wood treatment facility at Jerome. Fluoranthene and pyrene, in particular, peak 8 km downstream of Jerome, and it is possible that these compounds have migrated downstream over the decades since the wood creosote treatment facility ceased operations in about 1956.

The highest concentrations of the phthalate esters and the trace elements arsenic, cadmium, and zinc occurred at the Turner River background site where the organic carbon concentration was the highest. The normalized distributions of the phthalate esters and arsenic, cadmium, and zinc suggest that their concentrations are influenced by widespread processes such as atmospheric transport of the phthalate esters; the natural distribution of arsenic, cadmium, and zinc; and the tendency of many trace substances to adsorb onto organic matter. Within the Barron River Canal, normalized values of arsenic, chromium, copper, and zinc peaked at either CR-858 or Jerome. The normalized concentrations of lead, copper and zinc at some sites indicate that they may be enriched above natural levels by human activities.

Concentrations of SVOCs and trace elements were below criteria that indicate potential adverse effects on aquatic life. However, most sites had measurable concentrations of several compounds, some of which approached the probable effect levels. Mixtures of SVOCs and other contaminants found at some sites could behave synergistically to cause adverse biological effects that are not indicated by criteria recommended for each individual contaminant.

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RELATIONSHIP BETWEEN DUROPHAGY AND FEEDING BIOMECHANICS IN GRAY TRIGGERFISH, *BALISTES CAPRISCUS*: INTRASPECIFIC VARIATION IN ECOLOGICAL MORPHOLOGY

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Abstract: *The relationship between oral jaw biomechanics and consumption of hard prey was compared between Gulf of Mexico (Gulf) and Atlantic Ocean (Atlantic) populations of gray triggerfish (*Balistes capriscus*) to examine intraspecific ecomorphological variation between these fish. Gut content analysis revealed that Atlantic fish fed more on hard-shelled invertebrates, such as crabs and sea urchins, than Gulf conspecifics. Difference in the relative magnitude of durophagy between Gulf and Atlantic triggerfish was associated with intraspecific differences in key biomechanical properties of the prey-capture and processing mechanism. The more durophagous Atlantic *B. capriscus *had more massive jaw bones and muscles than Gulf fish. The mechanical advantage of the lower jaw appeared to be less reflective of the dietary differences between fish from both locations. We hypothesize that *B. capriscus *has the ability to alter the development of its feeding mechanism to match the requirements for capturing and processing locally available prey-resources at post-recruitment habitats in the Atlantic and Gulf coasts of Florida.*

The central theme of ecomorphological studies is understanding the functional-ecological relationship between an organism and its environment. In fishes, previous studies have shown that the constructional design of feeding mechanisms constrain the diversity of prey that can be consumed because the functional morphology of the feeding mechanism underlies the ability of fishes to capture and process prey (Liem, 1991; Turingan and Wainwright, 1993). Key features of the feeding apparatus, such as oral-jaw gape (Hoyle and Keast, 1988), pharyngeal-jaw gape (Wainwright, 1988), pharyngeal-jaw crushing strength (Wainwright, 1987, 1988), and oral-jaw crushing strength (Turingan, 1994; Hernandez and Motta, 1997) have been shown to reflect the size, hardness and elusiveness of prey consumed by fishes. However, most studies that attempted to relate functional morphology to ecology were conducted at the interspecific level of analysis. We know very little about the extent to which within-species variation in ecomorphology exists.

Many species of marine-coastal fishes inhabit a variety of post-recruitment habitats. Although conspecific fish collected from different locations have been shown to exhibit different food habits, the association between intraspecific differences in prey consumption and intraspecific differences in feeding biomechanics has not been thoroughly investigated. Previous experimental studies on lacustrine fishes (e.g., cichlids [Meyer, 1990] and centrarchids [Mittelbach et al., 1999]) have demonstrated that phenotypic-developmental plasticity underlies diet-induced changes in feeding morphology. A recently concluded study on the effects of two contrasting diets on the development of feeding biomechanics in sheepshead (*Archosargus probatocephalus*) from Florida is the first known experimental study on a marine-coastal fish species that demonstrated a similar diet-induced phenotypic plasticity (M. Fougerolle, unpublished MS thesis). In this study, we examined two populations of gray triggerfish (*Balistes capriscus*) located in the Atlantic Ocean and the Gulf of Mexico. In general, *B. capriscus* has a durophagous feeding habit, consuming hard-shelled invertebrates such as barnacles and sea urchins (Vose, 1990; Vose and Nelson, 1994). It has also been shown that *B. capriscus* is an opportunistic feeder, having the ability to switch between soft prey (e.g., polychaetes) and hard prey (e.g., crabs and barnacles) depending on the relative abundance of these prey organisms in different locations (Frazer et al., 1991; Vose and Nelson, 1994). This study addresses two specific questions: (1) Is there a difference in the relative consumption of hard prey (durophagy) between Atlantic and Gulf populations of *B. capriscus*? (2) If so, is intraspecific variation in durophagy associated with intraspecific difference in feeding biomechanics?

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MATERIALS AND METHODS—Representative Atlantic Ocean *B. capriscus* were collected off the coast of Cape Canaveral, Florida (28°32′45″ N, 81°30′0″ W). Collection sites were dominated by hard bottom structures such as artificial and natural reefs; predominant invertebrate prey included hard-shelled mollusks, crabs and sea urchins (Vose, 1990; Vose and Nelson, 1994). Gulf of Mexico *B. capriscus* were caught in Tampa Bay (27°32′0″ N, 82°47′0″ W) and off Turkey Point (29°53′0″ N, 84°28′0″ W), Florida. Collection sites in the Gulf were characterized by soft-bottom communities that included polychaetes, soft corals, sand dollars and bivalve mollusks (Frazer et al., 1991; Posey et al., 1998).

The gastro-intestinal tract of each triggerfish was dissected and examined. To minimize sampling bias associated with hook and line, the main method of fish collection, only fish that had at least 75% full stomach (based on visual inspection of stomach fullness under a dissecting microscope) were included in the dietary analysis. Furthermore, pieces of squid and fish used as bait were carefully eliminated before quantifying the relative contribution of natural prey in the diet of *B. capriscus*. Gut contents of 20 Atlantic and 33 Gulf fish were classified into 12 prey categories (Echinoidea, Asteroidea, Bivalvia, Gastropoda, Cirripedia, Polychaeta, crab, shrimp, Ophiuroidea, Porifera, Anthozoa and algae). The volumetric contribution of each prey category was calculated by water displacement, as outlined in Turingan (1994). Difference in magnitude of durophagy between Atlantic and Gulf *B. capriscus* was determined by comparing the average consumption of hard prey (i.e., pooled volumetric contribution of Echinoidea, Bivalvia, Gastropoda, Cirripedia, crab, Ophiuroidea).

The same fish (including 10 more Gulf caught *B. capriscus*) used in the dietary analysis were measured for standard length (SL) and biomechanical features of the oral-jaw apparatus. Oral-jaw bones (upper and lower jaws) and muscles (adductor mandibulae 1 and 2) were

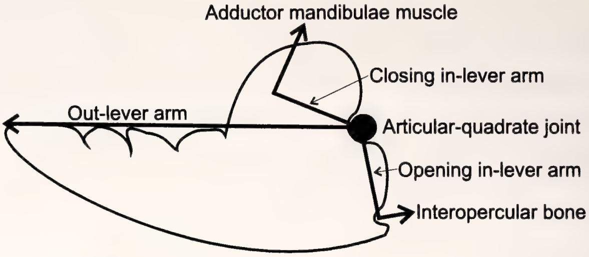

FIG. 1. Schematic diagram of *B. capriscus* lower jaw, showing the distances (out-lever, closing in-lever, and opening in-lever) measured to quantify mechanical advantage.

dissected from the left side of the head, patted dry with a paper towel and weighed to the nearest 0.01 gram using a Sartorius® analytical balance. The mechanical advantage (i.e., lever ratio) of the lower jaws was estimated from three linear measurements on the jaw bone (Wainwright and Richard, 1995; Turingan et al., 1995): (1) opening and closing out-lever was the distance between the articular-quadrate joint and the most anterior tip of the biting teeth; (2) opening in-lever was the distance between the articular-quadrate joint and the insertion point of the inter-opercular bone on the mandible; (3) closing in-lever was the distance between the articular-quadrate joint and the insertion point of the adductor mandibulae on the lower jaw (see Turingan et al., 1995 for details of this procedure; Fig. 1).

To remove the confounding effects of body size in intraspecific comparisons of feeding biomechanics, $\log_{10}$-transformed bone and muscle mass were compared between Atlantic and Gulf fish using Analysis of Covariance (ANCOVA), with $\log_{10}$-transformed SL as covariate. Interpopulation differences in arcsine-transformed jaw- opening and closing lever ratios were compared using Analysis of Variance. Graphical and statistical analyses were conducted using Sigmaplot® and Systat®, respectively (SPSS, Inc.).

RESULTS—Atlantic *B. capriscus* fed almost exclusively on hard-shelled invertebrates; on average, about 85% of prey consumed included echinoids, crabs, bivalves, gastropods, and Cirripedia (Table 1). In contrast, only about 55% of prey consumed by Gulf *B. capriscus* were considered hard prey, primarily infaunal bivalves. Exclusive of bivalves, errant polychaetes dominated the diet of Gulf *B. capriscus.* On average, Atlantic *B. capriscus* consumed relatively more hard prey than Gulf conspecifics (t-test to compare mean percentage volumetric contribution of hard prey: t = 2.901; df = 49,2; P = 0.004).

Mass of oral-jaw bones and muscles of individual *B. capriscus* at both locations increased with body size (Fig. 2; Table 2). Analyses of Covariance revealed that Atlantic *B. capriscus* had significantly higher upper and lower jaw mass, as well as adductor mandibulae 1 and 2 mass than Gulf conspecifics (Table 3). Of the two measures of mechanical advantage of the lower jaw, only the opening lever ratio was significantly different between the two *B. capriscus* populations.

DISCUSSION—Gray triggerfish, *B. capriscus* is an important component of the fish fauna along the Atlantic Ocean and Gulf of Mexico coasts of Florida. This ubiquitous species appear to successfully settle on different

TABLE 1. Mean percentage volumetric contribution (± SE) of prey consumed by *B. capriscus* in the Atlantic Ocean and Gulf of Mexico.

	Atlantic Ocean	Gulf of Mexico
Hard Prey		
Bivalvia	16.56 ± 6.37	38.26 ± 6.80
Cirripedia	10.27 ± 4.86	1.76 ± 0.68
Crab	25.70 ± 7.45	7.36 ± 3.16
Echinoidea	27.14 ± 8.53	6.10 ± 3.35
Gastropoda	2.72 ± 1.44	1.55 ± 0.51
Ophiuroidea	5.07 ± 4.46	0.00 ± 0.00
Soft Prey		
Algae	0.00 ± 0.00	0.12 ± 0.07
Asteroidea	5.00 ± 5.00	0.866 ± 0.866
Soft Coral	0.00 ± 0.00	2.18 ± 2.16
Polychaeta	4.98 ± 2.78	21.89 ± 4.32
Shrimp	0.00 ± 0.00	0.01 ± 0.01
Sponge	2.44 ± 1.76	0.00 ± 0.00
Unknown	0.114 ± 0.114	16.43 ± 3.22

habitats within its natural range of distribution (Vose, 1990; Frazer et al., 1991; Vose and Nelson, 1994). The ecomorphological analysis conducted in this study revealed three important characteristics of this species. First, *B. capriscus* in the Atlantic Ocean fed primarily on hard-shelled invertebrates that appear to dominate the prey-resource available on natural and artificial reefs characteristic of this habitat. Second, *B. capriscus* in the Gulf of Mex-

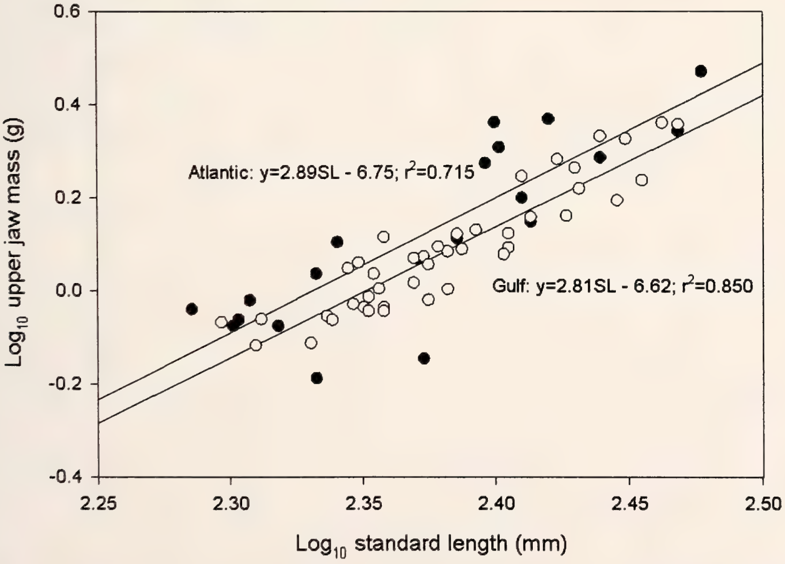

FIG. 2. Representative covariate regression plot showing the relationship between jaw bones and muscles in *B. capriscus*.

TABLE 2. Summary of regression analyses of the $\log_{10}$ transformed biomechanical variables on $\log_{10}$ transformed Standard Length of *B. capriscus* caught in the Atlantic Ocean and Gulf of Mexico.

Biomechanical variable	Location	Y intercept	Slope	R^2	P
Upper Jaw Mass	Atlantic	−6.75	2.89	0.715	$\ll 0.001$
	Gulf	−6.61	2.81	0.850	$\ll 0.001$
Lower Jaw Mass	Atlantic	−6.73	2.85	0.752	$\ll 0.001$
	Gulf	−6.86	2.88	0.854	$\ll 0.001$
Add. Mandibulae 1 Mass	Atlantic	−7.02	3.19	0.909	$\ll 0.001$
	Gulf	−6.48	2.93	0.754	$\ll 0.001$
Add. Mandibulae 2 Mass	Atlantic	−5.88	2.74	0.858	$\ll 0.001$
	Gulf	−7.02	3.21	0.875	$\ll 0.001$

ico included more soft prey invertebrates, such as errant polychaetes and soft corals in their diet. Third, difference in magnitude of durophagy between Atlantic and Gulf *B. capriscus* was reflected in differences in key biomechanical features of the oral-jaw apparatus, such as jaw muscle and bone mass.

Several studies have concluded that at both intra- and interspecific levels of analysis, there is a strong positive association between key features of feeding mechanism and food habits in fishes (Motta, 1988; Turingan et al., 1995; Wainwright and Richard, 1995). It has been argued that the validity of conclusions drawn from ecomorphological analyses become apparent only if the choice of functional morphological variables is based on knowledge of their biological and ecological roles (Turingan, 1994; Norton et al., 1995). Here we categorized prey consumed based on predator's method of prey

TABLE 3. Results of Analysis of Covariance comparing the mass of oral-jaw bones and muscles as well as Analysis of Variance comparing opening and closing lever ratios between Atlantic and Gulf *B. capriscus*. Sample mean values for the jaw-bones and muscles are adjusted for a 239.9 (± 1.0 SE) mm fish.

	Mean ± (SE)		Statistical comparison
Jaw Bone and Muscle Mass	Atlantic (n = 20)	Gulf (n = 43)	
Upper Jaw (g)	1.39 ± 1.04	1.20 ± 1.03	ANCOVA: F = 11.10; d.f. = 1,60; P = 0.001
Lower Jaw (g)	1.13 ± 1.04	0.99 ± 1.02	ANCOVA: F = 9.56; d.f = 1,60; P = 0.003
Add. Mand. 1 (g)	3.64 ± 1.04	3.14 ± 1.02	ANCOVA: F = 11.62; d.f. = 1,60; P = 0.001
Add. Mand. 2 (g)	4.47 ± 1.03	4.01 ± 1.02	ANCOVA: F = 9.22; d.f. = 1,60; P = 0.004
Mechanical Advantage			
Opening Lever Ratio	0.18 ± 0.00	0.15 ± 0.00	ANOVA: F = 13.92; d.f. = 1,61; P = <0.001
Closing Lever Ratio	0.27 ± 0.00	0.25 ± 0.00	ANOVA: F = 2.93; d.f. = 1,61; P = 0.092

capture and processing (e.g., the predator would bite and crush hard prey such as crabs and bivalves, whereas it would suction feed on soft, elusive prey such as errant polychaetes [Turingan and Wainwright, 1993]). In addition, we chose biomechanical properties of the oral jaws that are directly linked to feeding performance. For example, mass of the oral-jaw adductor muscle reflects force-producing capability, oral-jaw bone mass is indicative of compressive strength, and lever ratios represent a compromise between speed of jaw movement and biting strength (Barel, 1983; Wainwright, 1987, 1988; Turingan, 1994; Wainwright and Richard, 1995; Turingan et al., 1995; Hernandez and Motta, 1997).

Although the quantification of substratum type and invertebrate communities in the Atlantic and Gulf sites was beyond the scope of this study, it is hypothesized that differential consumption of hard prey between populations of *B. capriscus* reflected difference in the relative abundance of prey organisms in these two locations. As opportunistic predators, most fishes likely feed on the most abundant prey available in their foraging habitats. Results of our dietary analysis were consistent with previous reports on the food habits of *B. capriscus* in the Atlantic Ocean and Gulf of Mexico. Vose (1990) and Vose and Nelson (1994) also found that the main dietary items of *B. capriscus* located in the Atlantic Ocean were bivalves and barnacles (Cirripedia). In contrast, Frazer and co-workers (1991) found that *B. capriscus* inhabiting the Gulf of Mexico fed primarily on sand dollars.

Is variation in magnitude of durophagy between Atlantic and Gulf *B. capriscus* associated with between-location difference in the biomechanical features of the prey-capture and processing mechanism? It is likely that difference in prey-resource base and food habits between the two *B. capriscus* populations influenced the development of different feeding biomechanical designs between conspecifics. The relatively more massive oral-jaw bones and muscles of Atlantic *B. capriscus* appear to give them the ability to capture and process the hard-prey invertebrates that dominate their diet. Several studies have shown that feeding on different prey types induced changes in the development of feeding mechanisms: sticklebacks (Lavin and McPhail, 1986), cichlids (Greenwood, 1965; Meyer, 1987, 1989; Wimberger, 1991; Smits, 1996) and *A. probatocephalus* (M. Fougerolle, unpublished MS thesis). Muscle and bone physiology responds to changes in dynamic loading (Goldspink and Howells, 1974; Goldspink and Ward, 1979; Currey, 1984; Lanyon and Rubin, 1985). Vertebrate striated muscle hypertrophies in response to increased loads, resulting in increased mass and physiological cross-sectional area (Goldspink, 1983). Vertebrate bone tissue also has the ability to remodel and gain mass and size when subjected to increased stress (Wolff, 1892; Moore, 1965; Smith, 1981; Bouvier and Hylander, 1981; Beecher et al., 1983). Feeding on benthic, hard-shelled prey requires a forceful bite to capture prey and repeated chewing to crush prey before being swallowed (Turingan and Wainwright, 1993; Wainwright and Turingan, 1993; Turingan, 1994; Turingan et al., 1995; Cutwa, 1997; Hernandez and Motta, 1997). During prey capture and processing, jaw muscles and bones experience a loading regime that could induce them to increase mass and size (Turingan et al., 1995).

In addition to hypertrophy of jaw bones and muscles, increased durophagy would be expected to correlate with increased mechanical advantage of the lower jaw (i.e., lever ratio indicates the trade-off between speed of jaw movement and transmission of force from the adductor mandibulae muscle to the biting surface of the jaw). Although this trend has been demonstrated in interspecific comparisons (Westneat, 1990, 1994; Turingan, 1994; Wainwright and Richard, 1995), we found that intraspecific difference in jaw closing lever ratios were not consistent with the pattern seen in oral-jaw bones and muscles. However, there was a significant difference in opening lever ratios between Gulf and Atlantic fish. This could be attributed to the difference in opening in-lever arm between the two triggerfish populations (ANCOVA to compare average opening in-lever arm: $F = 18.966$; df $= 1,60$; $P = <0.001$). We hypothesize that subtle differences in the hardness of prey consumed by conspecifics in the wild induced hypertrophy of bones and muscles, but had inconsistent effect on the lever systems of the lower jaw. Perhaps during development, mechanical advantage of the lower jaws is less responsive to difference in magnitude of durophagy in *B. capriscus.*

The ability of *B. capriscus* to alter its feeding habits is coupled with its ability to alter the development of its feeding mechanism to match the demands for prey capture and processing of locally available prey. Intraspecific variation in ecomorphological patterns may be as widespread in fishes as the existence of interspecific variation. This has important implications for our understanding of the mechanisms that underlie the ability of a fish species to successfully occupy heterogeneous habitats such as those found within the range of distribution of *B. capriscus* in Florida.

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POTENTIAL BREAKUP OF FLORIDA PLANT COMMUNITIES AS A RESULT OF CLIMATIC WARMING

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ABSTRACT: *Plant community breakup is defined as the extent to which one or more physiognomically dominant plant species are lost from their communities. With respect to climatic change, potential plant community breakup can be measured as the extent to which one or more climatic envelopes (i. e., climatic adaptation zones) of dominant plant species are lost from the natural ranges of their communities. A climatic-envelope model is used to predict potential breakup of 13 major natural plant communities in Florida as a result of six climatic-change scenarios that could occur over the next 100 years. Averaged over all communities and species within communities, the high-to-low ranking of potential community breakup by scenario is as follows: T+2w (80) > T+1 (80) > T+2w > T+2 > T+1w > T+1 > T, where T = baseline; T+1 and T+2 = mean annual warming of 1°C or 2°C, respectively, applied uniformly to each month; T+1w and T+2w = mean annual warming of 1°C or 2°C, with proportionately greater winter and less summer warming (i. e., winter-enhanced or "w"); and (80) = 80% of the baseline mean annual precipitation. The 61% to 100% loss of at least one dominant species envelope caused by T+1 (80) in 11 of the 13 communities and of at least two dominant species envelopes in seven communities is especially notable because it involves only a 1°C increase. Based on consideration of non-climatic factors such as persistence time of temperate species and migration rates of subtropical species during climatic change, we conclude that T+1 (80) or any of the +2°C scenarios is likely to produce: (1) very significant modification or breakup of several major, natural, woody communities in the Florida panhandle and upper two thirds of the Florida peninsula; and (2) an increase in certain dominant, subtropical species populations in the southern half of the Florida peninsula. Methods of monitoring for early indications of such impacts are noted, and proactive mitigations are suggested. Areas of special interest with respect to monitoring and mitigation include a transition zone between temperate species of two different range types in the Florida panhandle and upper peninsula, and both a major and secondary temperate-subtropical species transition zone in the southern half of the Florida peninsula.*

PALEOECOLOGICAL evidence from the late Quaternary Period indicates that species often responded to global climatic change according to their individual climatic tolerances (Graham, 1992). Paleovegetational analyses of the eastern United States provide evidence that coexisting plant species responded differently, and that entire plant communities did not shift as tightly linked species groups (Davis, 1981). As an apparent result, some plant communities that previously existed in the southeastern United States have no modern analogues and vice versa (Delcourt and Delcourt, 1985). Thus future climatic warming in Florida, which is in the extreme southeastern United States, might cause serious breakup of existing plant communities due to differential responses of their physiognomically dominant species.

Moderate to large in-situ losses of current species climatic envelopes or "zones of climatic adaptation" in Florida have been predicted for a number of ecologically important, temperate woody species, as a result of several types of 1°C and 2°C warming (Box et al., 1999). This suggested that the accompanying breakup of several major terrestrial and wetland communities in Florida could be extensive. This analysis is extended in the present report to predictions of the loss of physiognomically dominant plant species envelopes from their respective plant community ranges, in order to provide more direct estimates of warming-induced potential community breakup. Non-climatic factors such as temperate species persistence and subtropical species migration, in a warmer climate, are then considered in order to make general inferences about the actual amount of community modification, breakup, and replacement that might occur.

METHODS—Plant communities can be defined by the required occurrence of at least a minimum number of their main structural elements (Box, in press). A plant community begins to lose its integrity or "wholeness" when any of these elements (e. g., *Fagus grandifolia* or *Acer saccharum* in a Beech-Maple Forest of eastern North America) begins to lose fitness. This process of losing community integrity causes varying amounts of community breakup. For the purposes of this report, we will define community breakup as the loss of some amount of area of one or more dominant plant species from the natural range of their community. The amount of plant community breakup predicted for any major woody, terrestrial or wetland, plant community in Florida under climatic warming can then be measured as percent loss of one or more dominant woody species from that part of the community's natural range which contains the species.

This analysis concerns physiognomic dominants, i. e., plant species which areally dominate the upper canopy and appearance of vegetative communities and, presumably, exert some degree of control over other species (e. g., by controlling access to resources such as light, water, and nutrients; for additional discussion, see Barbour et al., 1987). "Subcanopy dominants" from lower canopy levels, and codominants are also referred to herein as dominant species in their communities.

Climatic-envelope loss can be used to predict potential community breakup due to climatic warming. A species climatic envelope is defined as the climatic bounds within which a species can grow and reproduce under natural conditions, with an additional assumption that the geographical boundary of a species' climatic envelope approximates the natural range of the species (see later part of Methods for justification). The amount of actual community breakup over a certain period of time following climatic change will also depend on the ability of dominant temperate species to persist in the changed environment.

The predicted climatic-envelope loss of a temperate species from its community was measured by comparing (1) the predicted climatic-envelope area of the species that occurs within the natural range of its community under a particular climatic-warming scenario with (2) the present or "baseline" climatic-envelope area of the species that occurs within the community. Sixty-nine percent of such comparisons in the present report were obtained by manual overlays of the appropriate climatic-envelope and community range maps, using a technique that measured map areas to within 1% of areal measurements produced by a Geographical Information System. This produced "point" estimates of percent envelope loss (e. g., 0, 22, 47, 65, or 100). In order to broaden the analysis, we subsequently added some dominant species, and results from the T+1w scenario. This remaining 31% of the comparisons produced estimates of the range of percent loss (i. e., 0–20, 21–40, 41–60, 61–80, or 81–100). These "range" estimates are less precise because they involved the use of maps that had not been transformed to a Universal Transverse Mercator projection. Their precision is quite adequate for the purposes of this report. All predicted species climatic-envelope losses from their respective communities are, therefore, presented as "range" estimates in Fig. 1, in order to facilitate comparisons.

Predictions of potential community breakup under climatic warming were made for 13 of the major plant communities described in the USDA Soil Conservation Service's 1981 manual, "26 Ecological Communities of Florida." The Soil Conservation Service (SCS) essentially defines these communities as vegetated ecosystems. SCS then identifies them on the basis of their major plant communities but usually names them by major vegetation type (e. g., "North Florida Flatwoods" and "Swamp Hardwoods"; in some instances, such as "Longleaf Pine—Turkey Oak Hills", and "Cabbage Palm Hammocks", species common names are included). We chose this community classification because it provided a relatively large number of major woody plant communities to choose from, reasonably detailed descriptions of important woody species in each community, and large natural range maps for each community. Furthermore, this material can be easily cross-referenced to (1) the "General Map of Ecological Communities—State of Florida" (USDA Soil Conservation Service, 1980), the "General Map of Natural Vegetation of Florida" (Davis, 1967), the small maps provided in "Ecosystems of Florida" (Myers and Ewel, 1990); and (2) expanded community descriptions in later publications such as the Florida Natural Areas Inventory and Department of Natural Resources (1990) "Guide to the Natural Communities of Florida", various articles in "Ecosystems of Florida", Johnson and Muller (1992), Johnson and co-workers (1990), and Schwartz (1994).

The typical dominant species chosen for analysis is one described by SCS as "characterizing" its community; i. e., one which "so commonly occurs in a community that you would expect to see it there at most locations supporting that community" (USDA Soil Conservation Service, 1981). Important dominant species were added for some communities, based on discussions in the above-mentioned community references. Nearly all of the species included were, however, described as being a community dominant or codominant in at least one of the references (and often in more than one). Some species are dominant only in certain community subtypes, e. g., *Pinus taeda* (loblolly pine) in early successional stages of Mixed Hardwood and Pine, and *P. serotina* (pond pine) in poorly drained parts of North Florida Flatwoods.

We predicted the loss of dominant species from their communities under each of six climatic-change scenarios, as follows (where T= mean annual baseline temperature in °C): T+1 and T+2 (mean annual warming of 1°C or 2°C, respectively, applied uniformly to each month); T+1w, T+2w (mean annual warming of 1°C or 2°C, with proportionately greater winter and less summer warming—i. e., winter-enhanced or "w"); and T+1 (80), and T+2w (80), where (80) represents 80% of baseline mean annual precipitation. Additional discusssion of these scenarios is provided in Box and co-workers, 1999.

Predictions of potential species loss were made by using the "Florida Plant Species—Climatic Envelope Model" (Box et al., 1993, 1999), often referred to subsequently as the "Florida Model" or, more simply, the "Model." The Florida Model contains climatic envelopes for 124 of the most common and/or characteristic native woody species in Florida, including all of the dominant species involved in our community breakup analysis. Each species envelope is defined by the upper and lower limits for each of eight potentially important climatic variables, as follows: mean temperature of warmest and coldest months and annual range of mean monthly temperature TMAX, TMIN, DTY (°C); mean minimum temperature of coldest month and absolute minimum temperature, TMMIN and TABMIN (°C); average annual precipitation and average precipitation of driest month, PRCP and PMIN (mm); annual moisture index, MI (PRCP/average annual potential evapotranspiration).

The Florida Model assumes that a species will not grow and reproduce at a site if the value of any of the climatic variables at that site exceeds either the upper or lower envelope limit of the species. The Model is an empirical, deterministic, equilibrium model that was built by associating mostly 20th century climatic data with the natural range data of Little (1978).

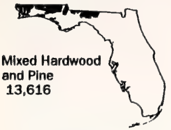
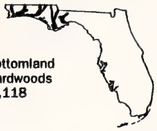
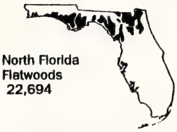
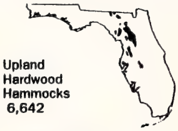
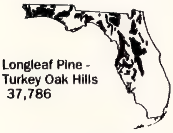
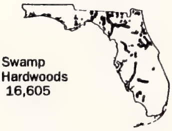
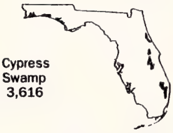
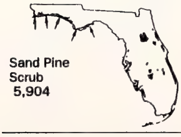
Ecological Community	Dominant Species	Scenario					
		T+1	T+1w	T+2	T+2w	T+1 (80)	T+2w (80)
 Mixed Hardwood and Pine 13,616	*Fagus grandifolia*	0-20	81-100	81-100	81-100	81-100	81-100
	Magnolia grandiflora	21-40	0-20	81-100	0-20	61-80	41-60
	Pinus echinata	81-100	81-100	81-100	81-100	81-100	81-100
	Pinus palustris	0-20	0-20	0-20	0-20	0-20	41-60
	Pinus taeda	0-20	0-20	0-20	41-60	0-20	41-60
	Quercus falcata	0-20	0-20	0-20	81-100	0-20	81-100
 Bottomland Hardwoods 8,118	*Carya aquatica*	0-20	0-20	0-20	0-20	21-40	41-60
	Quercus laurifolia	0-20	0-20	0-20	0-20	21-40	41-60
	Quercus michauxii	0-20	0-20	0-20	41-60	61-80	81-100
	Salix nigra	0-20	81-100	81-100	81-100	81-100	81-100
 North Florida Flatwoods 22,694	*Pinus elliottii* var. *elliottii*	0-20	0-20	0-20	21-40	41-60	81-100
	Pinus palustris	0-20	0-20	0-20	0-20	41-60	81-100
	Pinus serotina	0-20	0-20	0-20	21-40	61-80	81-100
 Upland Hardwood Hammocks 6,642	*Carya glabra*	0-20	0-20	0-20	81-100	81-100	81-100
	Liquidambar styraciflua	0-20	0-20	0-20	41-60	81-100	81-100
	Magnolia grandiflora	21-40	0-20	81-100	61-80	81-100	81-100
	Quercus hemisphaerica	0-20	0-20	0-20	0-20	0-20	21-40
 Longleaf Pine - Turkey Oak Hills 37,786	*Pinus palustris*	0-20	0-20	0-20	21-40	61-80	61-80
	Quercus incana	0-20	0-20	0-20	21-40	0-20	21-40
	Quercus laevis	0-20	0-20	0-20	21-40	0-20	21-40
 Swamp Hardwoods 16,605	*Acer rubrum*	0-20	0-20	0-20	21-40	0-20	41-60
	Nyssa sylvatica	0-20	0-20	0-20	21-40	81-100	81-100
	Taxodium distichum	0-20	0-20	0-20	0-20	61-80	81-100
 Cypress Swamp 3,616	*Nyssa sylvatica*	0-20	21-40	21-40	61-80	61-80	61-80
	Salix caroliniana	0-20	0-20	41-60	41-60	0-20	41-60
	Taxodium distichum	0-20	0-20	0-20	41-60	61-80	81-100
 Sand Pine Scrub 5,904	*Pinus clausa*	0-20	0-20	21-40	41-60	61-80	61-80
	Quercus chapmanii	0-20	0-20	0-20	41-60	0-20	41-60
	Quercus geminata	0-20	0-20	21-40	41-60	41-60	61-80
	Quercus myrtifolia	0-20	0-20	21-40	41-60	0-20	41-60

FIG. 1. Predicted climatic-envelope loss (%) of physiognomically dominant or codominant temperate species from the natural ranges of major forested, terrestrial and wetland, communities in Florida. Under scenario T+1, e. g., 0% to 20% of *Fagus grandifolia* is predicted to be lost from the 13,616 km^2 baseline natural range of Mixed Hardwood and Pine. Individually small polygons for certain communities and/or the general location of such polygons are identified by arrows on the community maps. Stippling is used on the Tropical Hammocks map to emphasize the scattered, somewhat infrequent occurrences of this community.

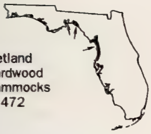
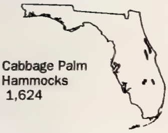
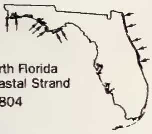
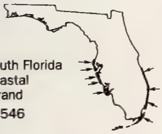
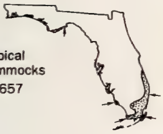
Ecological Community	Dominant Species	Scenario					
		T+1	T+1 w	T+2	T+2w	T+1 (80)	T+2w (80)
 Wetland Hardwood Hammocks 2,472	*Magnolia grandiflora*	41-60	0-20	81-100	61-80	81-100	81-100
	Quercus laurifolia	0-20	0-20	0-20	0-20	81-100	81-100
	Quercus nigra	0-20	0-20	0-20	21-40	81-100	81-100
	Quercus virginiana	0-20	0-20	0-20	0-20	0-20	0-20
 Cabbage Palm Hammocks 1,624	*Quercus virginiana*	0-20	0-20	0-20	0-20	0-20	21-40
 North Florida Coastal Strand 2,804	*Magnolia grandiflora*	41-60	0-20	81-100	41-60	81-100	61-80
	Persea borbonia	0-20	0-20	81-100	0-20	41-60	41-60
	Quercus geminata	0-20	0-20	0-20	0-20	0-20	41-60
	Quercus myrtifolia	0-20	0-20	0-20	0-20	0-20	0-20
	Quercus virginiana	0-20	0-20	0-20	0-20	0-20	0-20
 South Florida Coastal Strand 2,546	*Persea borbonia*	41-60	21-40	81-100	81-100	81-100	81-100
	Quercus geminata	21-40	41-60	81-100	81-100	81-100	81-100
	Quercus myrtifolia	21-40	21-40	81-100	81-100	21-40	81-100
	Quercus virginiana	0-20	0-20	21-40	0-20	0-20	41-60
 Tropical Hammocks 12,657	*Quercus virginiana*	0-20	0-20	61-80	81-100	0-20	81-100

FIG. 1. Continued.

It predicts with 99% mean accuracy the current natural ranges of 43 model "test"species, as indicated by their correct presence or absence within 100 km of 36 sites distributed throughout Florida (Box et al., 1993). Several types of additional evidence indicate that the Model captures much of the spatial variability of its plant species, even though Florida locations exhibit considerable variation in substrate and topography, as well as in climate (Box et al., 1993, 1999; Crumpacker et al., unpublished). At scales as coarse as those used in the present report to overlay maps, calculate envelope areas, and report envelope losses, we have therefore assumed that climatic-envelopes approximate species natural ranges for most species (exceptions usually involve species with special edaphic and/or topographic requirements).

Based on their current natural ranges as mapped primarily by Little, and their predicted responses to four types of climatic warming, the 124 species of the Florida Model can be divided into six natural range types, as follows: *Temperate Panhandle and/or Upper Peninsula* (28 spp.)—usually extending from the north southward into parts or all of the Florida panhandle and/or upper peninsula; *Warm Temperate* (53 spp.)—usually extending from the north southward into much or most of Florida, but usually not significantly south of Lake Okeechobee; *Subtropical* (31 spp.)—usually extending from the keys and Caribbean Islands into parts or all of the lower to central peninsula of Florida; *Warm Temperate—Subtropical* (5 spp.)—usually extending from the south northward into Florida, and beyond into the adjacent southeastern United States; and *Warm Temperate Coastal* (1 sp.) and *Subtropical Coastal* (6 spp.)—same as Warm Temperate and Subtropical, respectively, except largely restricted to coastal areas.

Community natural ranges in Fig. 1 were redrawn from maps in USDA Soil Conservation Service (1981) except for North and South Florida Coastal Strands, which were redrawn from maps of Davis (1967) and USDA Soil Conservation Service (1980). With respect to vegetative components, the USDA's term "Ecological Community" is analogous to a major plant community. Eleven of the 13 communities are composed primarily or entirely of temperate species whose climatic envelopes are predicted to contract with warming, thereby contributing to potential community breakup. The other two, South Florida Coastal Strand and Tropical Hammocks, contain a majority of subtropical species mixed with some temperate species (the former species are referred to as subtropical in order to agree more accurately with the subtropical nature of their ranges in Florida; Box et al., 1999). Our analysis of South Florida Coastal Strand and Tropical Hammocks predicts the amount of warming-induced loss of their temperate species components. These losses are based only on those parts of their natural ranges which occur in the peninsula and upper keys (losses from the lower keys were omitted because of difficulty in obtaining accurate areas of these community ranges from available maps). Even the analyzed areas of North and South Florida Coastal Strand communities are overestimated because of the difficulty in depicting their narrow, linear ranges on small-scale maps; however, this is expected to cause relatively little bias in the estimates of *percent* loss of climatic-envelope areas from these communities.

The USDA Soil Conservation Service (SCS) classification combines the different vegetation zones of the Coastal Strand communities into each of two major types, North and South Florida Coastal Strand, as opposed to other classifications such as that of Johnson and associates (e. g., Johnson and Barbour, 1990) which treat them separately. Although we retained the more inclusive SCS nomenclature, results for South Florida Coastal Strand in Fig. 1 are presented separately for its scrub (see *Quercus geminata* and *Q. myrtifolia*) and maritime hammock (see *Persea borbonia* and *Q. virginiana*) vegetation zones because of the very different distribution patterns of these zones on the Atlantic and Gulf Coasts (scrub from Brevard to Palm Beach Counties on the Atlantic, and maritime hammock from Brevard to Palm Beach counties on the Atlantic and from Pinellas to Collier Counties on the Gulf; see Johnson et al., 1990; Johnson and Muller, 1992).

Common names and authorities for all species in Fig. 1 are listed in Box and co-workers (1993). *Taxodium distichum, Nyssa sylvatica,* and *Quercus geminata,* respectively, include *T. distichum* var. *nutans, N. sylvatica* var. *biflora,* and *Q. geminata* var. *maritima,* which are considered by some botanists to be separate species or varieties of other species (Ewel, 1990; Johnson and Barbour, 1990). These taxa were not distinguished by Little (1978). *Sabal palmetto,* which is a dominant in communities such as Cabbage Palm Hammocks and North and South Florida Coastal Strand, is not included in Fig. 1 because it has a Warm Temperate—Subtropical (rather than temperate) range type. We did not analyze the largely subtropical South Florida Flatwoods community because of a large difference between its natural range as mapped by the USDA Soil Conservation Service (1981) and the natural range of its most important dominant, *Pinus elliottii* var. *densa* (*P. elliottii* var. *densa and P. elliottii* var. *elliottii* are treated as separate species in the Florida Model).

RESULTS—Predictions of potential community breakup are presented in terms of climatic-envelope loss in Fig. 1. Scenario T+1 causes low envelope losses of 0% to 20% for most temperate species dominants from most communities. Exceptions include between 21% and 60% loss of *Magnolia grandiflora* from each of the four communities in which it listed, 81% to 100% loss of *Pinus echinata* from Mixed Hardwood and Pine, and 21% to 60% loss of *Quercus geminata, Q. myrtifolia,* and *Persea borbonia* from their respective scrub (*Quercus* spp.) and maritime hammock (*Persea* sp.) zones of South Florida Coastal Strand. The losses of the first two of the above species from Mixed Hardwood and Pine in northwest Florida are caused by different factors associated with the T+1 scenario, as follows: at some locations TMAX has an upper model limit slightly too high for *M. grandiflora,* whereas the upper limit of TMIN is slightly too high for *P. echinata* at most locations. *Quercus geminata, Q. myrtifolia,* and *P. borbonia* are near the southern limit of their Warm Temperate natural ranges in South Florida Coastal Strand and therefore susceptible to envelope loss with even a 1°C rise in temperature (their upper model limits for TMIN tend to be slightly exceeded in the more southern locations).

Scenario T+1w also causes low losses of 0% to 20% for most temperate species dominants from most communities. Important exceptions, which occur primarily in the Florida panhandle, involve 81% to 100% losses of *Pinus echinata* and *Fagus grandifolia* from Mixed Hardwood and Pine, and of *Salix nigra* from Bottomland Hardwoods. The very high losses of the latter two species, compared with their low losses under T+1, result from the enhanced winter warming of T+1w which raises TMIN above the Model's upper limits for these species at many locations. South Florida Coastal Strand exhibits between 21% and 60% loss of three species under T+1w. However, T+1w causes only slightly greater community breakup than T+1, when the predictions are averaged over all communities and species in Fig. 1.

T+2 produces losses of between 61% and 100% for at least one dominant species in seven of the thirteen communites, and of at least two dominants in three communities. Mixed Hardwood and Pine and South Florida Coastal Strand are again the hardest hit, with 81% to 100% losses of three dominant species each. In the former community, two of the three species have "Temperate Panhandle and/or Upper Peninsula" ranges, and are at or near the southern boundary of their eastern U. S. distribution. All three of the species with 81% to 100% losses from South Florida Coastal Strand are presently at or near the southern boundary of their Warm Temperate natural ranges.

Envelope losses of dominant species from communities under T+2w are generally greater than under T+2, although numerous instances occur when no difference is predicted. *Magnolia grandiflora* is an important exception, as it is predicted to experience less loss under T+2w than under T+2, from each of the four communities in which it is a dominant. T+2w proportionately lowers summer warming while proportionately enhancing winter warming, and thereby prevents TMAX from exceeding its upper model limit for *M. grandiflora* at various locations in the northern half of Florida.

T+1 (80) causes losses of between 61% and 100% for at least one dominant species from 11 of the 13 communities, and of at least two dominants from seven communities. The negative impact of T+1 (80), which lowers MI by combining a temperature increase with a precipitation decrease, tends to be greater than that of T+2 and T+2w. Important exceptions occur for (1) *Q. falcata* in Mixed Hardwood and Pine in relatively moist northwest Florida, where the negative effect on this species of increased winter temperature under T+2w is much more detrimental than the lowering of the moisture balance under T+1 (80); and (2) *Q. myrtifolia* in the scrub zone of South Florida Coastal Strand and *Q. virginiana* in Tropical Hammocks (both of these relatively drought-resistant species are much more seriously impacted by the large increase in TMIN associated with the T+2w scenario).

T+2w (80) is predicted to have the greatest negative impact on community integrity of any scenario investigated. It causes between 61% and 100% envelope loss of at least one dominant species in 12 of the 13 communities, and of at least two dominants in nine communities. T+2w (80) often produces more serious community breakup than T+1 (80). The only situations in which it is predicted to have a lower loss of dominant species than T+1 (80) involve *M. grandiflora* in Mixed Hardwood and Pine and in North Florida Coastal Strand.

DISCUSSION—The relative ranking of potential community breakup predicted for the climatic-warming scenarios in Fig. 1 is as follows (Eqn. 1).

$$\begin{aligned} &T + 2w(80) > T + 1(80) > T + 2w > T + 2 \\ &\qquad > T + 1w > T + 1 > T. \end{aligned} \tag{1}$$

The rankings are not uniform across communities, nor across species within communities, and various exceptions exist within these categories. It is especially important to note that an annual temperature rise of only 1°C distributed equally across seasons, but with a decrease of 20% mean annual precipitation, i. e. T+1 (80), has a potential community breakup impact that is generally greater than a 2°C annual warming that occurs proportionately more in winter (T+2w) or uniformly throughout the year (T+2). The predicted breakup with T+1 (80) is often much greater than for T+1 in comparisons among communities, as well as among species within communities.

If any of the +2°C warming scenarios or T+1 (80) occur, many of the populations of Florida communities discussed in this report are predicted to undergo great potential modification. Under T+2, e. g., three of the six dominant species listed for Mixed Hardwood and Pine in northwest Florida would experience a potential (i. e., climatic-envelope) loss of 81% to 100% from that community (Fig. 1). Under T+2w (80), all six of these dominants would undergo moderate to very high losses of 41% to 100%. South Florida Coastal Strand would experience 81% to 100% envelope loss of several dominant species from some of its important vegetation zones under any of the +2°C or T+1 (80) scenarios. Bottomland Hardwoods, Upland Hardwood Hammocks, Cypress Swamp, and Sand Pine Scrub are predicted to undergo envelope losses of between 41% and 100% for at least half of their dominant species under T+2w, T+1 (80), and T+2w (80). In addition to the widespread potential of T+1 (80) and T+2w (80) to cause extensive breakup of Florida's remaining natural communities, these scenarios are predicted to convert much of the naturally forested area of peninsular Florida to open woodland, scrub, or savanna (Box et al., 1999).

Evidence pertaining to the Florida Model's usefulness in predicting the relationship between climatic warming and woody plant species responses was mentioned earlier (Methods Section). But how credible are the +2°C and T+1 (80) scenarios that result in such large predictions of potential plant community breakup? A 2°C rise in global mean temperature by the year 2100 (with low and high estimates of +1°C and +3.5°C, respectively) is the "best" estimate of the Intergovernmental Panel on Climate Change 1995 or "IPCC" (Houghton et al., 1996). In this respect, our +1°C scenarios are conservative. Support for the disproportionately greater warming in winter associated with scenarios T+1w, T+2w, and T+2w (80) comes from two of the three General Circulation Model (GCM) predictions for a "doubled CO_2 climate" in the southeastern U. S., as surveyed by Smith and Tirpak (1989). "Winter-enhanced" warming is also consistent with the IPCC's tentative conclusion that global warming will lead to a decrease in winter days with extremely low temperatures (Kattenberg et al., 1996).

In a discussion of Florida climate under global warming, Palmer (1998) concluded that increases in both precipitation and drought are inevitable in a warmer world. He noted further that 50 more years of current global warming projections would produce a hotter and wetter Florida, with more floods and hurricanes. We included the warming plus drying scenarios, T+1 (80) and T+2w (80), in our Florida Model predictions not only to cover a wide range of plausible scenarios, but also because the three GCM climatic-warming projections used in Smith and Tirpak (1989) predicted a drier average annual climate for the southeastern United States. In fact, one of these projections predicted a 16% decrease in average summer precipitation for that region. Subsequently, preliminary results of Neilson and Marks (1994) indicated that eastern North America will be one of two global areas most sensitive to drought-induced forest decline. They suggested that increases of warming-induced potential evapotranspiration would more than offset increases of precipitation in eastern North America.

The actual amount of plant community breakup expected under the different warming scenarios investigated with the Florida Model will also depend on the extent to which the temperate dominant species of each community may be able to persist in the changed climates. This can be most appropriately considered over the next 100 years, which is approximately the time involved in the IPCC projections. Some of Florida's temperate dominant trees may live for 200 or more years. Thus, they are adapted to considerable short-term climatic variability. In addition to morphological and physiological acclimation of individuals, adaptation to climatic change might result from higher fitness of, e. g., more heat- and/or drought-resistant ecotypes within populations (also see Loehle and LeBlanc, 1996). Alternatively, the lowered climatic fitness of temperate dominant species is likely to increase the susceptibility of their populations to invasions by more heat tolerant species, both woody and herbaceous, and native and non-native. Woody, native examples of such species in the Florida Model include *Myrica cerifera* and *Serenoa repens.* The warmer winters expected with scenarios such as T+1w and T+2w could result in failure of adequate vernalization, cessation of dormancy, and exposure to serious insect and disease outbreaks in temperate woody species. The periods of drought, interspersed with an increase in severe storms, that would be expected under T+1 (80) and T+2w (80), might cause more intense wildfires, also associated with disease and insect epidemics. These kinds of alterations in historic disturbance regimes might speed up the loss of dominant species from their communities (also see Loehle and LeBlanc, 1996). Although some of Florida's woody C_3 species might benefit from CO_2 enrichment in a $2\times CO_2$ environment, others might not; furthermore, some invasive C_3 species might be favored (see discussion and references in Box et al., 1999). It is also important to note that the Florida Model underestimates overall fitness losses of its temperate woody species in warmer climates because it does not remove any portion of a species' envelope until the fitness of that part reaches zero (see Fig. 3 of Box et al., 1999). The above discussion suggests that the potential community breakup predicted to result from any of the +2°C or T+1 (80) scenarios over the next 100 years is likely to result in serious fitness losses of communities, if not in actual breakup.

The extent to which Florida's existing temperate plant communities might be replaced by new communities with dominant subtropical species over the next 100 years of predicted warming depends on the migratory ability of these subtropical species, as well as on the *in situ* persistence and resistence of temperate species, and the degree to which citizens would want to influence the process. Paleoecological evidence of northward tree migration over the past 15,000 years of warming in eastern North America (Davis and Zabinski, 1992; Webb, 1992), together with modeling of tree species migration (Schwartz, 1992; Iverson et al., 1999) suggests that Florida's native woody subtropical species would be unlikely to migrate on their own as much as 50 km north of their baseline locations over the next 100 years. Migration would be greatly impeded by the extensive fragmention of Florida's natural habitats (even though many subtropical species have seeds designed for avian dispersal). Thus community breakup, or extensive modification, through dominant species loss might well occur in the upper half of the Florida peninsula without replacement by subtropical species.

The greatest potential for natural replacement of temperate by subtropical species over the next 100 years would be in the current, major and secondary, temperate-subtropical transition zones of the southern half of the peninsula (Fig. 2). *Bursera simaruba* (gumbo limbo) and *Coccoloba diversifolia* (pigeon plum) are common canopy dominants currently found in most rockland hammocks of south Florida (Snyder et al., 1990), and in coastal outlier populations as far north as Cape Canaveral on the Atlantic and, for *B. simaruba,* Tampa Bay on the Gulf Coast (Little, 1978). *Ficus aurea*

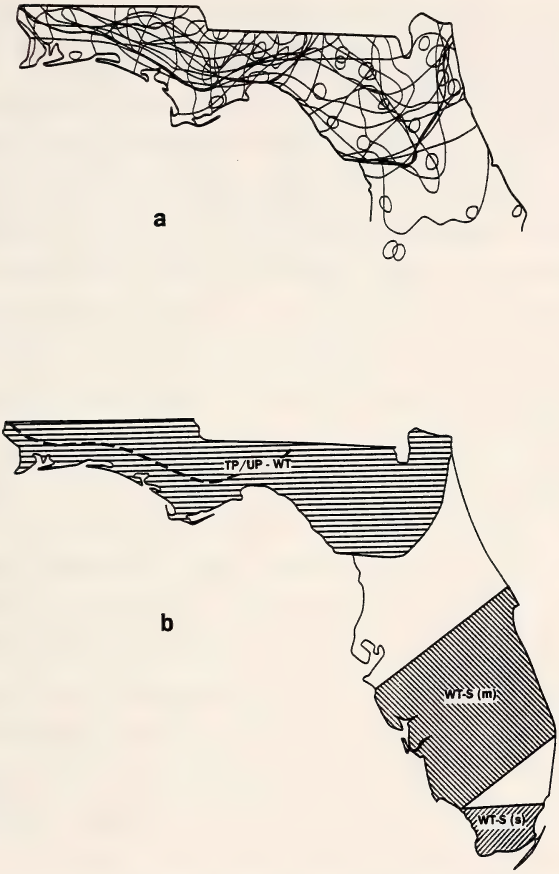


FIG. 2. (a) Southern boundaries of Florida natural ranges of 28 Temperate Panhandle and/or Upper Peninsula species in the Florida Model (see Appendix for list of species and Little, 1978 for natural range maps). (b) Temperate Panhandle and/or Upper Peninsula—Warm Temperate (TP/UP—WT) transition zone, and comparison with locations of the major (m) and secondary (s) Warm Temperate—Subtropical (WT—S) transition zones in the southern half of the Florida peninsula. (Positions of the Warm Temperate—Subtropical transition zones are based on unpublished data of Crumpacker, Box, and Hardin). The broken line in the TP/UP—WT transition zone designates the area of maximum range boundary concentration in that zone, and hence the expected region of maximum potential instability under climatic warming. The transition zone portion located above this unstable region is similar to the Southern Mixed Hardwood Forest Zone of Greller (1980), the high pine zone of Myers (1990), and the Mixed Hardwood and Pine community of the USDA Soil Conservation Service (1981) as shown in Fig. 1.

(strangler fig) also occurs widely in rockland hammock canopies and is common on the Miami rock ridge (Snyder et al., 1990). *Eugenia axillaris* (white stopper) is a very common, smaller subcanopy tree that occurs in virtually all tropical hardwood hammocks (Snyder et al., 1990). The latter two species currently range to or above Lake Okeechobee (in the east-central part of the major temperate-subtropical transition zone of Fig. 2b), with considerable coastward range extensions to Cape Canaveral and, for *F. aurea,* to Tampa Bay (Little, 1978; Box et al., 1999, column 1 of Fig. 4). With the exception of *C. diversifolia,* climatic envelopes for all of the above subtropical species cover most of the southern half of the peninsula under all of the warming scenarios included in the present report (Box et al, 1999, Fig. 4). One choice to be made might be whether to mitigate community breakup and failure of subtropical species migration by introducing subtropical species into deteriorating temperate species stands. Such actions should only proceed based on scientific considerations and public discussion (Box et al., 1999). Under a warming climate, the above-mentioned species should be excellent subtropical candidates for introduction programs as far north as the Interstate Highway 4 development corridor that extends from Tampa, through Orlando, to Daytona Beach.

Although most of the subtropical species mentioned above also occur in some of the pinelands of south Florida, the only canopy dominant in that ecosystem is the subtropical *Pinus elliottii* var. *elliottii* (south Florida slash pine) (Snyder et al., 1990). This taxon ranges throughout much of the potentially forested areas of the upper two-thirds of the Florida peninsula, where it is commonly dominant in pine flatwoods communities. Farther north, it is replaced in these communities by the dominants *Pinus elliottii* var. *elliotti* (slash pine) and *P. palustris* (longleaf pine) (see column 1 of Fig. 4 in Box et al., 1999 for natural range maps of these species). Of all subtropical taxa that could potentially move north with climatic warming, *P. elliottii* var. *densa* is the one which appears to have the greatest potential for natural replacement of temperate dominants (because of the many places in which it is already in close contact with such species).

We have noted elsewhere (Box et al., 1999; Crumpacker et al., unpubl.) that an "early-warning" monitoring system of ecologically important, native woody species could be instigated now, in order to provide time for consideration and implementation of mitigation measures needed with climatic warming. Some examples of potentially important mitigations that we recommended are as follows: (1) *completion of an interlocking system of conservation areas in the major temperate-subtropical transition zone of the south central peninsula* (see Fig. 2b for location of this zone), where some of the most serious negative impacts from climatic warming are expected to occur first; (2) *scientifically-assessed and publicly-supported use of land and water protection methods that allow as much management flexibility as possible* (some examples are control of non-native plant species invasions stimulated by climatic warming; thinning of deteriorating temperate species stands; assistance with northward and inland migration and establishment of native subtropical plant species; and curtailment of land drainage with provision of supplemental irrigation in key areas); and (3) *ecological restoration, assisted by purchase of less expensive options to buy future linkage areas that will also need restoration.*

Special attention should also be given to conservation activities in the panhandle and northern peninsula of Florida. In this region, a number of Model species, with Temperate Panhandle and/or Upper Peninsula range type, are at or near the southern boundary of their natural ranges in the eastern United States. In Fig. 1, the dominants *Fagus grandifolia, Pinus echinata, P. taeda,* and *Quercus falcata* of the Mixed Hardwood and Pine community, and *Q. michauxii* and *Salix nigra* of Bottomland Hardwoods are examples of such species. A Temperate Panhandle and/or Upper Peninsula—Warm Temperate species transition zone exists in this region (Fig. 2). In this zone, communities change from ones involving coexistence of Temperate Panhandle and/or Upper Peninsula species with Warm Temperate species to those that contain mostly or entirely Warm Temperate species. If climatic warming occurs, species stands of Temperate Panhandle and/or Upper Peninsula range type would be some of the first to undergo deterioration *in situ.* Co-existing Warm Temperate species might then be expected to begin expanding within these deteriorating stands, although many Warm Temperate species would also begin to deteriorate to a lesser degree. This situation is likely to be more disruptive than the one involving the Warm Temperate—Subtropical transition zone at the southern tip of the peninsula (Fig. 2b) because only a very few dominant, Warm Temperate species coexist with Subtropical dominants in the latter location. Moreover, Subtropical species would be able to replace the deteriorating Warm Temperate species more easily in a warming climate, even though they too might encounter some fitness losses under T+1 (80) and T+2w (80) (Crumpacker et al., unpubl.). Monitoring for signs of warming-induced instability should also be initiated in the Florida panhandle and upper peninsula, to be followed as necessary with proactive mitigations. Several of these mitigations might be the same as those suggested previously for the major temperate—subtropical transition zone in the southern half of the Florida peninsula.

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APPENDIX

The 28 Temperate Panhandle and/or Upper Peninsula species in the Florida Plant Species—Climatic Envelope Model[1]

Acer barbatum, Alnus serrulata, Carya pallida, Castanea alnifolia, C. pumila, Chamaecyparis thyoides, Fagus grandifolia, Fraxinus americana, F. pennsylvanica, F. profunda, Ilex myrtifolia, Juglans nigra, Kalmia latifolia, Nyssa aquatica, N. ogeche, Ostrya virginiana, Oxydendron arboreum, Pinus echinata, P. glabra, P. taeda, Platanus occidentalis, Quercus alba, Q. durandii, Q. falcata, Q. marilandica, Q. michauxii, Q. shumardii, Salix nigra.

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[1] See Appendix 1 of Box and co-workers (1993) for scientific and common names, and authorities, for all species in the Florida Model.

EFFECT OF CONCENTRATION AND DECOMPOSITION TIME ON THE PHYTOTOXICITY OF CATTAIL (*TYPHA DOMINGENSIS*) EXTRACTS

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ABSTRACT: *The effect of concentration and decomposition time on the phytotoxic properties of aqueous extracts of a cattail species was examined. Cattail tissues contained water-soluble materials that were toxic to germination and growth of lettuce and cattail seeds. A strong correlation was found between extract concentration and toxicity. At very low concentrations, cattail aqueous extracts stimulated germination and root elongation, but, as the concentration increased, the phytotoxic effects became apparent. The phytotoxic effects observed included germination inhibition, inversion of the seedlings, and inhibition of growth. The extracts became generally more toxic after a week of decomposition at 23°C. Longer decomposition time, however, made the extracts less active. Addition of increasing amounts of activated charcoal removed the phytotoxic properties; there was a direct correlation between the amount of adsorbent used (0–1.5g) and the decrease in phytotoxicity under the conditions of the bioassay.*

CATTAILS, *Typha* spp. are the most dominant of the emergent species of aquatic plants in Florida public waters (Schardt, 1997). To understand the expansion of the opportunistic *Typha,* several factors need to be considered, including its size, growth habits, adaptability to changes in the surroundings (nutrient levels, hydroperiod, shade), and the release of chemical compounds able to prevent the growth of other species (Gallardo et al., 1998).

There is ample evidence regarding the presence of a number of biologically active substances in cattail tissue. Alliota and co-workers (1990) successfully isolated three steroids (β-sitosterol, (20S)-24-methylenlophenol and stigmast-4-ene-3,6-dione) and three fatty acids (linolenic, linoleic and an unidentified $C_{18:2}$) from organic extracts of *T. latifolia.* Several free and acylglucosilated stigmasterols were also found in *T. latifolia* (Della Greca et al., 1990a). The oxidation pattern of the stigmasterols corresponds to that obtained by microbial oxidation of cholesterol (Bridgeman et al., 1970), and suggests the presence in the cattail of an enzymatic system able to transform β-sitosterol into the sterols reported. However, it is also possible that these compounds are being produced through an autooxidation process of β-sitosterol and stigmast-4-ene-3,6-dione. The structure of (20S)-4α-metylene-cholest-7-en-3β-ol, another sterol isolated from *T. latifolia* was determined by means of spectroscopic studies (Della Greca et al., 1990b). This compound (2μmol) was tested in a paper disk bioassay against two cyanobacteria, *Anabaena flos-aquae* and *Chlorella vulgaris,* and the compound was found to be a growth inhibitor for these two species.

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Eleven kinds of phenolic compounds were detected in female flowers of *T. latifolia* (Ozawa and Imagawa, 1988). The compound present in higher concentration was 5-*trans*-caffeoylshikimic acid. Other phenolic substances isolated and identified were epicatechin and afzelechin, but their relative amounts were very low.

Even though the aforementioned phytotoxins have been isolated and their inhibitory potential has been determined, the study of cattail phytotoxicity has thus far been inconclusive due to apparent contradictions between experimental evidence. For each study that reports phytotoxic effects of cattail extracts or by-products, there exists a counterpart that denies such findings.

McNaughton (1968), working with *T. latifolia,* found evidence of autotoxicity when cattail seeds were germinated in the presence of aqueous extracts of cattail leaves. Moreover, he showed that upon treatment with an adsorbent material, the autotoxic effect could be eliminated. In 1978, Van der Valk and Davis found evidence of autotoxicity of *T. glauca,* but Sharma and Gopel (1978) failed to find the same response when studying *T. angustata* and *T. elephantina.* Grace (1983), in an evaluation of the work of McNaughton, found no conclusive evidence for the autotoxic effect.

The work of Szcepanska (1971,1987) has been an important contribution to the understanding of the allelopathic potential of cattails. By planting mixed cultures of *T. latifolia* and other aquatic weeds (specially *Phragmites australis*), the interactions between these plants were determined on the basis of growth and production characteristics. The results provide evidence of a phytotoxic effect of cattails on the other wetland species.

Prindle and Martin (1996) found aqueous extracts of *T. domingensis* could inhibit the germination of lettuce and radish seeds; the extracts also inhibited oxygen production when added to the medium containing *Lyngbya majuscula.* Observed phytotoxic properties were conserved upon autoclaving; 2-chlorophenol and salicylaldehyde were identified as two major components in these extracts (Prindle et al., 1997). In contrast, Bonasera and co-workers (1979) found very low inhibitory effects when testing aqueous extracts of *T. latifolia* against lettuce, radish, cucumber, and tomato seeds. Elakovich and Wooten (1989) found similar results against lettuce seeds and duckweed.

Recently, we have found inhibitory effects of cattail on the growth and oxygen production of *Salvinia minima* (Gallardo et al., 1998), and also detrimental effects of cattail on the germination of other wetland species. In our own experience, there are many sources of variability that could account for the contradictory literature. The phytotoxins produced by aquatic macrophytes are neither highly specific nor very potent (Muller and Chou, 1972). Seasonal variations (Dolling et al., 1994), phytochemical induction and uptake of compounds of anthropogenic origin (Gallardo et al., 1999) are some of the major sources of variability, together with inconsistencies in the extraction procedure. After some preliminary experiments, it became apparent for us that, in order to obtain meaningful data, all the factors had to be considered, and the negative impacts minimized. With this in mind, we cultured the cattail specimens used in this work in a controlled growing environment.

The purpose of this research was to study the phytotoxic properties of cattail extracts and to establish a useful phytotoxicity range. Manipulation of the phytotoxic effects by means of chemical adsorbents and by preparing extracts of variable concentrations was undertaken in order to determine if the extracts follow the mathematical models that have been proposed for allelopathic substances (An et al., 1993). We were also interested in the changes in the phytotoxicity of the extracts that could be induced by microbial degradation (Muller and Chou, 1972; Mason-Sedum et al., 1986.). Overall, our comprehensive approach provides basic information on the chemical mechanisms that contribute to cattail expansion.

METHODS AND MATERIALS—*Cattail extracts*—Fully mature samples were taken from a pond near the University of South Florida campus in Tampa, Florida. Samples were identified, and, after collection, were maintained in half-strength Hoagland's medium (Steward and Elliston, 1973) in a controlled environment Phytotron room (Environmental Growth Chambers, Chagrin Falls, Ohio) for a month prior to use. The conditions in the growth chamber were as follows: constant temperature (26°C), 12 h photoperiod with a light intensity of 190 $\mu E \cdot m^{-2} \cdot sec^{-1}$ (as measured by a LI-COR model LI-185A photometer) at ground level and 80% relative humidity. The plants were set in plastic trays (59 cm L × 40.5 cm W × 17 cm H) and acid-washed sand was used as a solid support. To prepare the extracts, a portion of the root system (not including rhizomes) was harvested from the growth chamber, rinsed with deionized water and extracted in a blender with deionized water at room temperature. The plant material/water ratio of the extracts varied depending on whether the extracts were prepared for the activated charcoal bioassay (1:5 constant ratio) or for the concentration/decomposition time bioassay (ratios varied incrementally between 1:50 to 1:1).

Activated charcoal studies—A cattail extract was prepared in the manner described, in a ratio of 5 mL of water per gram of fresh material. Mixtures of cattail extract (10 mL) with activated charcoal (Mallinckrodt, St. Louis, Missouri) were prepared by adding incremental amounts of solvent-extracted charcoal to flasks containing the cattail extracts. The flasks were placed in a New Brunswick model G76 gyrorotary shaker bath for 2 hrs. After this period of time, the mixtures were centrifuged, and the supernatant was filter-sterilized (Micropore, 0.22 μm), stored in the refrigerator at 0–4°C, and used for the subsequent bioassays.

Concentration/decomposition time studies—Aqueous extracts of increasing concentration were prepared using cattail root material from the growth chamber. For the initial concentration-dependence study, extracts were filter-sterilized while fresh, their total organic carbon and total phenolic content were determined, and then the extracts were used to set up a bioassay against lettuce seeds. For the decomposition time studies, extracts were prepared in the same manner, but not filtered, and then set in the growth chamber, in uncovered Erlenmeyer flasks for 7 and 14 days. After the decomposition time was completed, the extracts were centrifuged, and the supernatant was filter-sterilized and used in the bioassays.

Determination of organic carbon—Analyses of the cattail extracts were done using a Dohrmann (model DC-180) automated carbon analyzer. Aqueous extracts used in the concentration bioassay were analyzed for organic carbon content. Calibration was done using potassium hydrogen phthalate in deionized water, serially diluted from 2,000 ppm to give a 10-ppm working standard. The concentration of organic carbon was then calculated.

Phenolic content—A 10- mL volume of filtered sample or standard reagent grade phenol (Aldrich Chemical Company, Inc., Milwaukee, Wisconsin) solution were mixed with 1.5 mL sodium carbonate (1.9 *M*) and 0.5 mL Folin-Ciocalteau phenol reagent (Sigma Chemical Company, St. Louis, Missouri). Mixtures were allowed to stand in darkness at room temperature for 1 hr, then the absorbance was measured (Spectronic 20, Bausch and Lomb, Rochester, New York) at 750 nm against distilled water, and corrected for the absorbance of a distilled water reagent blank (Box, 1983; Blum et al., 1991).

Bioassays with lettuce seeds—Germination inhibition bioassays were performed using lettuce seeds (var. Black Seeded Simpson) (Fredonia Seeds, Chattanooga, Tennessee). Lettuce seeds have been used for the detection of phytotoxicity (Moon and Martin, 1981; Rice, 1984; Leather and Einhellig, 1986; Prindle and Martin, 1996) because of their availability, reproducibility, and high germination rates. The seeds were disinfected by rinsing successively in a 5% solution of commercial bleach for 1 min, followed by 5% Alconox in water for 1 min, and finally distilled water until no residual foam was observed. Then, 10 seeds were placed on each well of a 3-cm diameter well tray that was fitted with sterile disks of Whatman #1 filter paper. Aseptic conditions were maintained at all times. First, 1.5 mL of distilled water was dispensed into each well of the well tray with a sterile pipette; then 0.5 mL of the extract being tested was added to the well. Each of the test substances was replicated twice, in a randomized design. The control wells received 0.5 mL of distilled water, and there were 3 control wells on each tray. The trays were then wrapped in clear Saran Wrap and kept under constant cool white light (170 $\mu E \cdot m^{-2} \cdot sec^{-1}$). The trays were aerated, and the moisture replenished every day. Every other day, the number of germinated seeds and orientation of the seedlings was recorded. Root elongation measurements were taken after a week. At that point, the seedlings were dried at room temperature for two days to obtain the dry weight. The bioassays were repeated, always randomizing the position of the test solutions in the wells. Data were evaluated using Student's *t* test.

Bioassays with cattail seeds—Field-collected *T. domingensis* seeds were used in the same manner as lettuce seeds. Even though the same treatments were applied, only percent germination and dry weight data were collected, since the fragility of the cattail seedlings made it impossible to use root elongation as a measure of the observed effects.

RESULTS AND DISCUSSION—The evidence presented demonstrates the phytotoxic potential of fresh *T. domingensis* extracts. The phytotoxicity observed includes several effects, such as germination inhibition, inversion of the seedlings, root malformations, and inhibition of root elongation. By extracting cattail tissue with water, we tried to mimic the natural process of phytotoxin release in a more realistic manner than extraction with organic solvents could accomplish.

TABLE 1. Modulation of the phytotoxic effects of cattail extracts by addition of activated charcoal. Effect on lettuce seeds*.

Treatment	Germination after 7 days (%)	% inversion	Dry weight (g)
Control (distilled water)	98 ± 5	3 ± 3	0.0139 ± 0.0011
Cattail root extract	33 ± 10	63 ± 15	0.0101 ± 0.0015
Cattail root extract + activated charcoal			
0.05 g	58 ± 10	60 ± 14	0.0110 ± 0.0011
0.10 g	83 ± 5	53 ± 13	0.0118 ± 0.0014
0.15 g	70 ± 14	43 ± 10	0.0019 ± 0.0001
0.25 g	73 ± 10	25 ± 13	0.0125 ± 0.0003
0.50 g	83 ± 20	18 ± 5	0.0129 ± 0.0028
1.00 g	88 ± 15	0	0.0147 ± 0.0002
1.50 g	95 ± 10	3 ± 3	0.0132 ± 0.0011

* Mean of four replicates ± standard deviation.

Effect of activated charcoal on the phytotoxicity of cattail extracts—Table 1 summarizes the percent germination, percent inversion, and dry weight of lettuce seedlings after a period of seven days. It can be inferred that addition of activated charcoal removed the phytotoxic effects; hydrophobic organic material appears to be responsible for the observed phytotoxicity in the absence of charcoal. The percent germination, y, was a function of the amount (area?) of charcoal, x, used. [Specifically, $y = 48.3 + 88.6x - 40.7x^2$; $R^2 = 0.82$.].

The marked effect of the cattail root extracts on percent germination is modulated by the addition of the organic adsorbent. Even the lowest amount added has a significant impact in increasing the germination rates. However, the percent inversion remains relatively high and decreases at a slower rate than the overall germination. Stunted root growth of the seedlings that do germinate accounts for lower dry weights than the controls. The cattail extracts seem to induce a number of malformations of the root, which include inversion, excess pilosity or root hair development (in the most diluted solutions) and dark, stunted root tips in most cases. This effect, even though is the hardest one to quantify, seems to be the most persistent. Even in the case of the fraction treated with 1.5 g of activated charcoal, where germination percentages are not statistically different from the control, the roots do not appear (on visual inspection) to be identical to the control roots.

The decrease in phytotoxicity with addition of activated charcoal is in accord with the findings of other groups, viz., addition of activated charcoal to phytotoxic mixtures gave reduced phytotoxicity (Yu and Matsui, 1994).

Effect of extract concentration—When extracts of increasing concentration were prepared, we found that the organic carbon content of the extracts increased proportionally with the amount of cattail root that was used (Table

TABLE 2. Organic carbon and total phenolic content of cattail extracts.

Ratio of root material (g) to distilled water (mL)	Organic carbon content (ppm)	Total phenolics (as ppm phenol)
1:50	175 ± 2	13 ± 2
3:30	259 ± 1	32 ± 1
4:50	380 ± 1	40 ± 2
5:50	518 ± 5	47 ± 4
10:50	769 ± 2	113 ± 6
20:50	1104 ± 3	200 ± 1
30:50	1506 ± 1	262 ± 3
40:50	1928 ± 5	323 ± 5
50:50	2510 ± 2	399 ± 1

2). However, the total phenolic content of the extracts increased at a slower rate. This effect appears to be related to the low solubility of most phenolic phytotoxins (mainly phenolic acids) in water. However, we believe that our extraction procedure provides a realistic representation of the "available" (Blum et al., 1991) phenolic compounds present in the water in a natural system at a given time.

When the extracts were bioassayed against lettuce seeds, it was found that the phytotoxic effects followed the mathematical models suggested by An and co-workers (1993). At very low phytotoxin concentrations, the extracts were stimulatory to germination and growth; as the concentrations increased, the extracts became inhibitory (See Table 3 and Fig. 1). In this case, graphs can be constructed that approximate the proposed allelopathic response. The model implies that as concentration changes, the relative domination of stimulation and inhibition by the allelochemical mixture is altered, and that the biological response of the test organism (the biological property of the allelochemical) will comprise responses to both stimuli. The response is also highly organism-specific (An et al., 1997).

This is particularly clear if we consider root elongation as a diagnostic parameter (An et al., 1997). Even at concentrations that reduce the percent of germinated seedlings, the net effect on root elongation is stimulatory (Table 3, 10:50 ratio, the net effect on root elongation is stimulatory, and the dry weight is not statistically different from the control, but the percent germination is only 38%).

In order to assess the real ecological significance of these findings, bioassays were performed using cattail seeds as test organisms. Results for the cattail seed bioassays are presented (Table 4). In general, the cattail seeds follow the same percent germination and dry weight trends as the lettuce seeds, which seems to indicate that the observed effects correlate well for the two species. However, in the case of the cattail bioassay, the standard deviations of the measurements are higher than for the lettuce, indicating the non-domesticated nature of the seeds used. Larger variations between

TABLE 3. Change in the phytotoxicity of cattail extracts with increasing decomposition time. Effect on dry weight and percent germination of lettuce seedlings.

Ratio of root material to distilled water (g/mL)	Decomposition time of the extract					
	Fresh extract		7-day extract		14-day extract	
	Dry weight (g)	% Germination	Dry weight (g)	% Germination	Dry weight (g)	% Germination
Control (0:50)	0.0093 ± 0.0034	98 ± 5	0.0126 ± 0.0025	95 ± 6	0.0101 ± 0.0009	98 ± 5
1:50	0.0093 ± 0.0015	95 ± 6	0.0129 ± 0.0019	93 ± 5	0.0101 ± 0.0012	98 ± 5
3:30	0.0123 ± 0.0025	73 ± 6	0.0130 ± 0.0010	86 ± 5	0.0111 ± 0.0003	98 ± 5
4:50	0.0101 ± 0.0013	60 ± 8	0.0140 ± 0.0004	78 ± 10	0.0105 ± 0.0018	95 ± 6
5:50	0.0122 ± 0.0043	53 ± 10	0.0131 ± 0.0009	68 ± 10	0.0139 ± 0.0004	93 ± 10
10:50	0.0111 ± 0.0018	38 ± 5	0.0119 ± 0.0036	70 ± 6	0.0103 ± 0.0005	95 ± 10
20:50	0.0120 ± 0.0002	40 ± 4	0.0127 ± 0.0030	83 ± 20	0.0107 ± 0.0004	92 ± 6
30:50	0.0111 ± 0.0030	35 ± 13	0.0096 ± 0.0020	75 ± 5	0.0113 ± 0.0026	88 ± 10
40:50	0.0099 ± 0.0012	30 ± 14	0.0082 ± 0.0019	47 ± 10	0.0126 ± 0.0007	78 ± 13
50:50	0.0090 ± 0.0003	18 ± 13	0.0090 ± 0.0009	50 ± 8	0.0102 ± 0.0004	73 ± 10

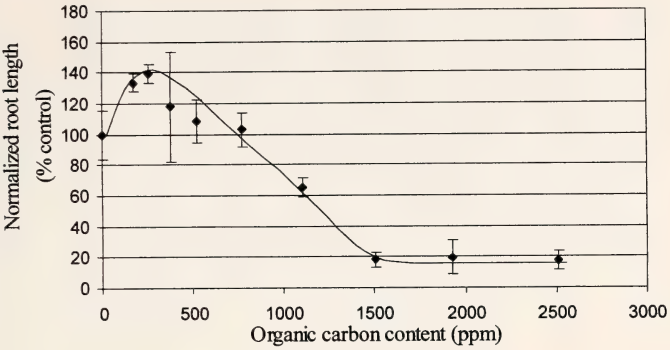

FIG. 1. Effect of increasing concentrations of cattail extracts on the root length of lettuce seedlings. Mean values ± S.E.

individuals in the wild population are responsible for more scattered data. Cattail seedlings are also very fragile, and for this reason root elongation was not determined for the cattail bioassay.

In practical terms, these findings serve to reconcile the conflicting literature. Small differences in concentration can mean a different response; different test organisms and the parameters used to evaluate the effect also become important (Inderjit and Dakshini, 1995; Romeo and Weidenhamer, 1998). Inconsistencies in the literature can be attributed to differences in sampling times, extract preparation, sources of plant material, and extract concentration. It is important to standardize the actual concentration of the extracts under study in order to make meaningful a correlation between different sets of data.

Effect of decomposition time on the phytotoxicity of the cattail extracts—The phytotoxic effect on root elongation increased with decomposition time in the first week of the study (Fig. 2), and decreased afterwards. However, the effect of the extracts on germination inhibition was less than the effects of the fresh extract (see Tables 3 and 4). This observation accounts for higher dry weights, since more seedlings were germinating, but with less viability because those seedlings that germinated had short, stunted roots. Without the root elongation data, it would appear as if the 7-day decomposition of the extract removed the phytotoxic properties, but upon inclusion of these data, it becomes apparent that the microbial decomposition actually serves to increase the phytotoxicity of the extracts. By propitiating a fitness-reducing event (Williams et al., 1998) that would eventually lead to increased mortality, the extracts are potentially useful as weed management agents.

After decomposition proceeded for 15 days, almost all inhibitory activity toward root elongation was lost, except for the most concentrated extract; germination inhibition was lower than for the fresh or 7-day extracts, and dry weights showed little variation. This trend—initial increase in toxicity

TABLE 4. Change in the phytotoxicity of cattail extracts with increasing decomposition time. Effect on dry weight and percent germination of cattail seedlings.

Ratio of root material to distilled water (g/mL)	Decomposition time of the extract					
	Fresh extract		7-day extract		14-day extract	
	Dry weight (g)	% Germination	Dry weight (g)	% Germination	Dry weight (g)	% Germination
Control (0:50)	0.0066 ± 0.0020	95 ± 8	0.0075 ± 0.0031	96 ± 12	0.0069 ± 0.0036	92 ± 10
1:50	0.0078 ± 0.0027	95 ± 10	0.0074 ± 0.0046	95 ± 9	0.0064 ± 0.0018	98 ± 7
3:30	0.0077 ± 0.0031	93 ± 6	0.0079 ± 0.0026	91 ± 7	0.0069 ± 0.0010	98 ± 5
4:50	0.0070 ± 0.0041	79 ± 9	0.0066 ± 0.0023	85 ± 13	0.0072 ± 0.0016	96 ± 13
5:50	0.0065 ± 0.0036	62 ± 5	0.0068 ± 0.0024	86 ± 6	0.0076 ± 0.0025	95 ± 7
10:50	0.0067 ± 0.0049	56 ± 9	0.0063 ± 0.0017	79 ± 10	0.0077 ± 0.0015	92 ± 9
20:50	0.0057 ± 0.0031	47 ± 6	0.0048 ± 0.0032	73 ± 14	0.0080 ± 0.0035	91 ± 11
30:50	0.0049 ± 0.0040	42 ± 11	0.0039 ± 0.0021	75 ± 9	0.0080 ± 0.0016	77 ± 15
40:50	0.0050 ± 0.0016	39 ± 6	0.0036 ± 0.0026	69 ± 10	0.0086 ± 0.0037	70 ± 31
50:50	0.0021 ± 0.0017	25 ± 7	0.0017 ± 0.0011	64 ± 12	0.0085 ± 0.0033	71 ± 16

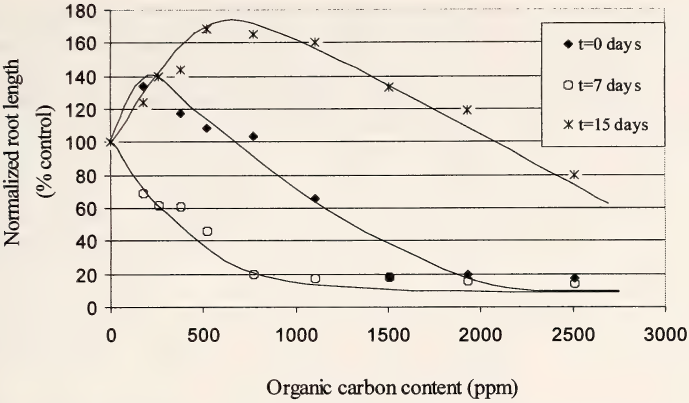

FIG. 2. Effect of decomposition time of cattail extracts of varying concentrations on root length of lettuce seedlings.

followed by decline probably due to microbial activity—is in general agreement with the literature (Mersie and Singh, 1987; An et al., 1997).

We believe that microbial decomposition plays an important role in the dynamics of the phytotoxic interaction of cattail with other species. In natural systems, continuous release of fresh toxins ensures the persistence of the phytotoxic effects, but microbial decomposition enhances the overall inhibition and broadens the spectrum of species that can be affected. Understanding the phytotoxic behavior of a species is a key factor in the formulation of viable herbicide-like materials and other useful products.

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THE MEDITERRANEAN GECKO, *HEMIDACTYLUS TURCICUS*: LIFE IN AN URBAN LANDSCAPE

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ABSTRACT: *Studies were conducted on the life history and ecology of the Mediterranean Gecko,* Hemidactylus turcicus *on the University of Tampa campus. Sex ratios did not differ significantly from 1:1. Reproductive females were collected as early as April.The reproductive season for most females lasts approximately 110 days. The first females with oviductal eggs were collected during May 9–11. About 41 days was required to produce a clutch of eggs. Results show ed that there is sufficient time for up to three clutches per season. Most males were reproductively active between June 9–Aug. 20. Mean testes weights were highest from April until July 27, ranging from 13.3–16.4 mg. Testicular mass decreased in early August. Growth rates for both sexes ranged from 0.8–6.9 mm/month. The smallest male with sperm in the ductus deferens was 42 mm SVL. The smallest female containing oviductal eggs or yolked follicles was 41.5 mm SVL. Juveniles were observed in early June and July, and occurred in greatest abundance in November. Population densities ranged from 497–1463 geckos/hectare. These geckos exhibited low vagility. There was no significant difference in survivorship between males and females, or between juveniles and adults. This lizard is a generalist predator and feeds on a wide variety of arthropods as well as gastropods. Peak activity occurred between 2100–2359 hr. The minimum distance between any two nests was 25 cm. Large spiders, whip scorpions, cats, bats, and Cuban tree frogs were observed capturing and feeding on these geckos.*

THE Mediterranean Gecko *Hemidactylus turcicus* Linnaeus is a nocturnal, insectivorous lizard naturally occurring on rocky cliffs in countries bordering the Mediterranean Sea and in other regions in the Middle East (Arnold et al., 1978). It was introduced into the United States less than a century ago, and was first recorded from Florida on Key West by Fowler (1915). It was first discovered in the vicinty of Miami (Dade County) in 1936 (Barbour, 1936), and was subsequently collected in Gainesville from wooden frame buildings on the University of Florida campus (King, 1958). As a result of human intervention, this successful colonizing species has subsequently spread throughout the Gulf coastal states (Davis, 1974; Conant and Collins, 1991) and as far west as Big Bend National Park (Easterla, 1978) and El Paso, Texas (Selcer, 1986). This gecko is frequently associated with man-made structures throughout its range.

Despite the broad geographical range of this species and its rather common occurrence in many localities, studies have tended to be fragmentary, and few have analyzed the life history of this species in any comprehensive way. Studies on relatively few populations have been conducted on the reproductive cycle (Rose and Barbour, 1968; Selcer, 1987, 1992; Meshaka, 1995), egg-body size relationships (Selcer, 1990), mating behavior (King, 1958), territoriality (Vaughn et al., 1996), feeding habits (Klawinski et al., 1994; Saenz, 1996), activity and movement patterns (Rose and Barbour, 1968), as well as population densities and sex ratios (Rose and Barbour, 1968; Selcer, 1986).

The most in-depth study of this gecko in the United States was conducted in Texas (Selcer, 1986). The results showed high population densities (544–2210/ha), low fecundity (1–3 clutches of two eggs/yr), and high adult survivorship (55% annual turnover, 3+ years life span).

One interesting and potentially important finding has indicated that individuals of *H. turcicus* do not generally disperse between buildings and as a result form rather discrete subpopulations (Nelson and Carey, 1993). This finding was confirmed by the detection of distinct differences in allele frequencies between populations of *H. turcicus* separated by only 100 m (Trout and Schwener, 1994).

The purpose of the present study was to conduct a detailed investigation on the natural history and ecology of an exotic population of *H. turcicus* in an urban environment.

MATERIALS AND METHODS—Studies were conducted on the campus of the University of Tampa (UT) which is situated in an urban environment adjacent to the downtown area. The campus, which comprises over 20 ha, is bordered on the east by the Hillsborough River. The climate in this area is subtropical with short, mild winters and long, hot summers. The temperature rarely falls below 8°C in the winter, and often rises above 38°C during the summer months.

I have been observing and collecting geckos from the entire UT campus for over 7 years, but the primary study areas in this study were man-made structures. One of these was a wooden building (320 m^2) that was once a one-room school house (SH) (Covington, 1981). The other was a one-story metal building (Krusen Bldg., KB; 3920 m^2) that has since been demolished for new construction. The distance between these two buildings was 25.2 m. I divided each building into 6 m grids marked with thin tape in order to record the locations and movement patterns of these lizards.

I conducted surveys 3–4 times per week throughout the year in 1997 and 1998, between dusk and dawn, concentrating my efforts between 2300–0300 hr. For each survey, I walked around both buildings until I had observed its entire surface.

I collected all lizards by hand or noosing, and provided each animal wih a unique identification by toe-clipping as described by Punzo (1974) in order to utilize mark-recapture methods for population analyses. I collected the following data for each lizard: date, location within a grid, time of capture (to assess diel periodicity), snout-vent length (SVL) using vernier calipers (to the nearest mm), weight (to the nearest 0.1g using an Ohaus Model 31677 Port-O-Gram electronic balance), reproductive condition, and sex. The sex of an adult animal was assessed by looking for the presence or absence of anal pores which are found only in males (Rose and Barbour, 1968). The reproductive condition of females was determined by the "candling" method as described by Selcer (1986). An individual is held and a beam of light from a flashlight is directed across the body. Due to the absence of a dark peritoneum, oviductal eggs and large yolked follicles can be identified through the body wall of this lizard. Each lizard was released at the site of capture within 20 min−1 hr.

Lizards used for histological examination and analysis of diet composition were collected from other buildings on campus (the science wing, SW, of Plant Hall; the boat house, BH; and the library, L), all within 20–40 m of the KB and SH, so as not to interfere with mark-recapture analyses. Geckos were frozen within 3 hr of capture, fixed in buffered formalin within 2 days, and then stored in 70% ethanol. I necropsied the lizards and measured the diam. of the ovarian follicles, testicular length, and SVL to the nearest 0.1 mm. I also used the presence of yolking follicles, oviductal eggs and corpora lutea (females), and coiled epididymus, enlarged testes, and the presence of sperm in the ductus deferens (males), as indicators of sexual maturity as described by Meshaka (1995) and Johnston (1999). I used the counts of yolked follicles or oviductal eggs to determine clutch size (Punzo, 2000a). The simultaneous presence of yolked follicles and oviductal eggs in a given lizard was taken as evidence for multiple clutches. Due to a low frequency of recaptures among reproductive females, clutch frequency was assessed indirectly as the length of the reproductive season divided by the length of time required to produce a clutch (Selcer, 1986). Relative clutch mass was defined as clutch mass divided by the total mass as discussed by Vitt and Price (1982).

Data from lizards captured and marked at the SH and KB sites were used to determine growth rates. Only animals captured on at least two occasions, and at least 21 days apart, were used in these analyses. The growth rate was determined by looking at the change in SVL between successive captures divided by the length of time between captures. The smallest lizard of each sex that was reproductively active was used to define minimum size at maturity. I estimated the age at maturity from animals marked as juveniles and subsequently recaptured as adults.

Previous observations (unpublished data) had indicated that the smallest size (SVL) required for *H. turcicus* to reach sexual maturity from this population was 43 mm. Following the method of Selcer (1990), I used the day corresponding to the point at which the growth line intersected with a horizontal line drawn at 43 mm as the date at which maturity was first attained.

I used the Schumacher-Eschmeyer method (Krebs, 1989) calculated from the mark-recapture data to estimate population sizes. This method is considered to be one of the most robust estimates for population size on closed populations (Seber, 1986). The percentage of geckos marked in 1997 which were recaptured in 1998 was used to estimate survivorship as described by Begon (1979). Other statistical procedures followed those of Sokal and Rohlf (1995).

I also made observations on real and potential predators, and various aspects of the behavior of these geckos including diel periodicity and nesting behavior. From preliminary observations I knew that these geckos prefer to nest underneath or inside man-made structures when these are available. Nests located in attics, within storage closets, abandoned drawers in desks and cabinets, crevices and holes in building walls and floor boards, behind boxes, and beneath piles of wood and other debris on floors, were counted and examined for the presence of eggs or egg shell fragments.

Stomach content analyses were conducted to determine the diet composition of adults. To obtain stomach samples, a total of 200 geckos were collected on three successive nights in late June from the BH and SW sites. This period was chosen because it lies well within the reproductive season, and previous observations had indicated that it also falls within a peak activity period for this lizard on the UT campus (pers. observ.). Geckos were collected, transported to the laboratory, sacrificed by injecting chloretone, and preserved in 10% buffered formalin. Subsequently, stomachs and intestines were removed and placed in ethanol until prey items could be removed and identified. Prey items were identified to Order and Family wherever possible, and diet composition expressed in terms of number of prey items for each taxon, percent by total number, percent by volume, and percent frequency as described by Punzo (1990). For each prey item, length (a) and width (b) were measured to the nearest 0.01 mm (excluding legs and antennae) and volume was determined using the formula for the volume of a prolate spheroid, $V = 4/3\ (a/2)(b/2)^2$, as described by Dunham (1983).

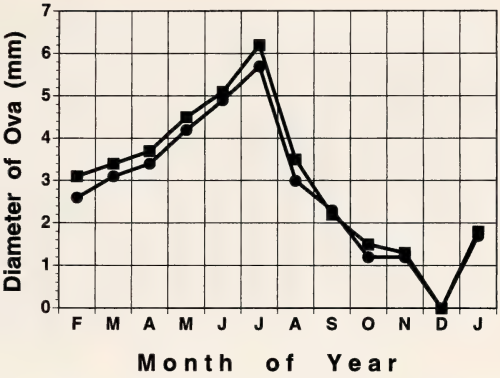

FIG. 1. Seasonal variation (February through January) in the size (diameter) of ova (in mm) from females of *Hemidactylus turcicus* from Tampa, Florida. Squares represent data for a typical female from 1997; circles represent data from 1998.

RESULTS—Data on lizards collected from both sites at 2-week intervals beginning on May 15 through Dec. 30 in 1997 (N = 225) and 1998 (N = 280) showed that in no instance did the ratio of males to females differ from 1:1 (X^2 = 2.01, P > 0.1). The earliest reproductively active female was collected on Apr. 3 in 1997, and on Apr. 8 in 1998. The latest were collected on Sept. 3 and Sept. 6, respectively. This data suggests that the reproductive season for *H. turcicus* at UT could last about 150 days. However, since samples containing over 50% reproductively active females were observed only between early May through mid-August, the reproductive season for most females may last for less than 110 days.

The first female containing oviductal eggs was collected on May 9 in 1997, and on May 11 in 1998. A total of 8 females in 1997, and 3 in 1998, contained corpora lutea, indicating recent oviposition. Combining these data with those above for the dates on which the earliest reproductively active females were collected, one can conclude that approximately 41 days are required to produce a clutch of eggs. Data collected from recaptured animals showed that four females contained oviductal eggs on two successive captures 38 days apart, suggesting that there is sufficient time for three clutches per season. Evidence for multiple clutches was provided from data on a total of 12 females (collected over the two—year period) that contained small yolked follicles and oviductal eggs simultaneously, and 9 lizards that similarly contained corpora lutea and yolked follicles. In addition, based on mark-recapture data, 5 females in 1997, and 3 in 1998, were observed to be reproductively active at two markedly diffrent times in one season (early June and late July). The mean relative clutch mass was 0.149 g (± 0.011 S.E., N = 44) in 1997, and 0.153 g (± 0.024, N = 37) in 1998. The seasonal variation in ova sizes is shown in (Fig. 1).

Fifty-two percent (130 out of 250) of the females necropsied over the two-year period contained yolked follicles or oviductal eggs, and 98% of

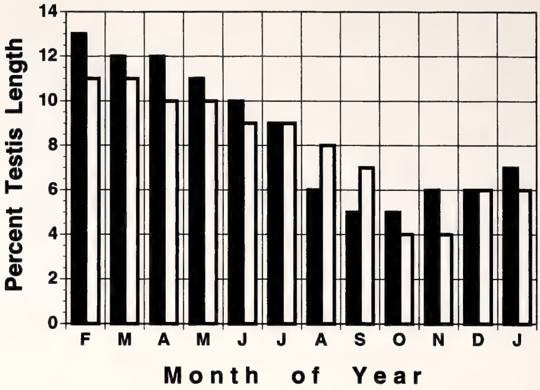

FIG. 2. Seasonal variation in the length of testes expressed as a percentage of snout-vent length of males of *Hemidactylus turcicus* from Tampa, Florida. Solid bars represent data from 1997; open bars are data from 1998.

them (N = 244) developed two follicles per clutch with one in each ovary. Among the other 6 females, some (N = 2) had one oviductal egg and two corpora lutea, while others (N = 4) contained two medium-sized (82–102 mg) yolked follicles in the right ovary and a small (< 70 mg) yolked follicle in the left ovary.

Sixty-six percent (168 out of 255) of the males collected were found to be reproductively active between June 9–Aug. 20. The mean testis weights were highest from Apr. until July 27, ranging from 13.3–16.4 mg (mean: 15.1 ± 0.89 S.E.) in 1997, and 11.8–16.8 mg (mean: 14.6 ± 1.77, N = 255) in 1998. In both years, the mean testis mass began to decrease in early Aug. (mean: 8.85 mg ± 1.04) and continued to decrease through the middle of Oct. (mean: 1.98 mg ± 0.03). Sperm were observed in the ductus deferens for up to 4 weeks after the initiation of testicular regression. Seasonal variation in the length of the testes is shown (Fig. 2).

The growth rates for 57 geckos ranged from 0.8–6.9 mm/month (mean: 2.03 ± 0.46 S.D.). No significant difference was found between the growth rates of males and females ($t = 0.17$, $P > 0.05$) (Fig. 3). Growth rates appeared to decrease as these geckos increased in size since growth rate was inversely related to SVL ($r = -0.71$, $P < 0.01$). Early in the season (May), over the 2-yr period, between 35–42% of all lizards sampled (1997 and 1998, respectively) had a SVL of 40–49 mm, and 57–63% had a SVL of 50–59 mm. Juvenile geckos (20–29 mm) were not seen until June 7th in 1997 (2%) and July 2nd in 1998 (14%). Conversely, juveniles were observed in greatest abundance in Nov. in both years (32 and 29%, respectively).

The smallest male with sperm in the ductus deferens was 42 mm SVL. The smallest female containing oviductal eggs or yolked follicles was 41.5 mm SVL. The age at sexual maturity in these populations ranged from 5.2–9.6 months (mean: 7.9 ± 0.97 months). Sixty-two percent of the geckos reached mature size during the spring, about 8 months after hatching the

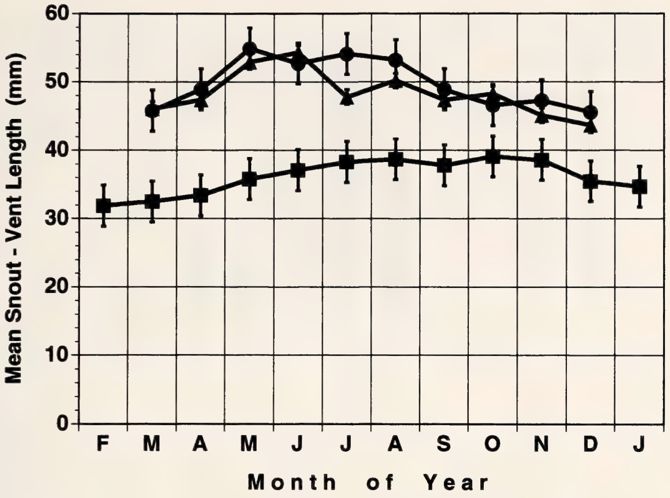

FIG. 3. Seasonal variation (from February 1997 to January, 1998) in snout-vent length for immatures (squares), males (circles), and females (triangles) of *Hemidactylus turcicus* from Tampa, Florida. Vertical lines represent S.E.M.

previous summer, and no geckos attained mature size during the winter months.

Over the 2-yr period, a total of 505 geckos were marked on the two study sites. There was a total of 724 captures with a mean of 1.8 captures/individual. The largest number of recaptures for any individual was nine, and 190 geckos (37.6%) were recaptured at least once. Population density estimates ranged from 387–502 for the SH site, and 1043–1402 for the KB, in 1997 and 1998, respectively. Expressed in terms of hectares, densities ranged from 497–1463 geckos/ha. Only three out of 55 geckos (5.4%) that were captured at least twice on the SH building were later captured at the KB site, even though the distance between these buildings was only 25.2 m. No geckos originally captured at the KB were subsequently recaptured at the SH. This low degree of dispersal indicates that these geckos do not travel far from their original hatching sites.

Twenty-four percent of the geckos marked in 1997 were recaptured in 1998. Adult survival for males and females was not significantly different ($G = 1.88$, $P > 0.05$). Similarly, no significant difference was found for survivorship between juveniles and adults ($G = 1.74$, $P > 0.05$). However, there was a significant difference in survivorship between smaller juveniles (< 30 mm SVL) and larger juveniles (31–39 mm) ($G = 12.12$, $P < 0.01$), indicating that mortality is significantly higher shortly after hatching in this species.

Numerous nests with eggs or egg shell fragments were located within the SH and KB in storage closets (N = 8), cabinet drawers (N = 5), boxes containing paper products and other items (N = 14), crevices in floor boards

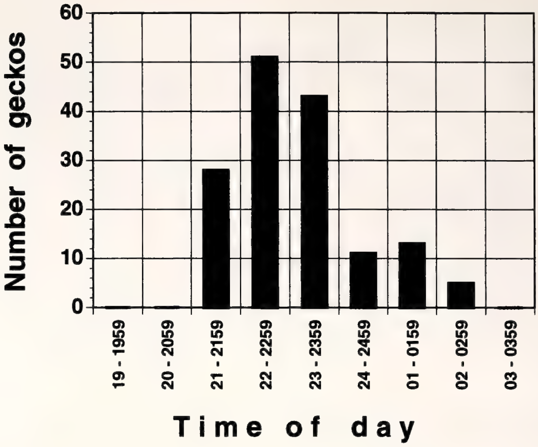

FIG. 4. Temporal patterns of activity for the gecko, *Hemidactylus turcicus*. Data represent the number of geckos active at various times of the day (EST).

and walls (N = 2), and beneath piles of wood and other surface debris (N = 11). Nests were also located under the SH building (N = 5). Egg numbers within a nest ranged from 2–14 and many nests (62%) were reused over the 2-yr period. Eggs were often covered to varying degrees with fragments of old egg shells, shed skins, dead leaves, soil particles, and/or bits of paper. The minimum distance between any two nests was 25 cm.

Most geckos were active between 2100–2359 hr EST (Fig. 4). Activity decreased markedy between 2400–0259 hr. No lizards were active between 0300 and 2059 hr in any year.

A number of predators were observed capturing geckos including bats of undetermined species (N = 2), Cuban tree frogs (*Osteopilus septentrionalis*, N = 7) large heteropodid crab spiders (*Heteropoda* sp., N = 12), a large wolf spider (*Hogna carolinensis*), a giant whip scorpion (*Mastigoproctus giganteus*) , and feral domestic cats (N = 2). These geckos often congregate on buildings near electric lights which attract insects and other arthropods. This would increase their visibility to avian and amphibian predators. Bats may utilize the calls made by these lizards to pinpoint their location. Spiders could locate a moving gecko by detecting vibrations with their array of sensitive mechanoreceptors.

These lizards are generalist predators and consume a wide variety of arthropod prey (Table 1). No significant differences were found between the diets of males and females. The most common prey taxa included flies (Diptera), spiders, roaches (Blattoidea), beetles (Coleoptera), moths (Lepidoptera), orthopterans, ants (Formicidae), and snails (Gastropoda). Geckos were attracted to outdoor lights which attracted a variety of arthropods. The same individuals were frequently recaptured where these lights were located suggesting that they defend these feeding stations against conspecifics.

TABLE 1. Analysis of stomach contents of the gecko, *Hemidactylus turcicus* from Tampa (N = 200 adults).

Prey taxon	Number of prey	Percent total number	Percent by volume	Percent frequency
Arachnida				
Araneae	52	11.6	10.1	24.0
Chilopoda	7	1.6	0.6	0.4
Isopoda	12	2.6	1.1	6.0
Gastropoda	24	5.3	3.1	9.0
Insecta				
Blattoidea (N, A)	37	8.3	6.7	15.5
Coleoptera				
Carabidae (A)	3	0.6	0.3	1.5
Scarabaeidae (A)	10	2.2	3.1	5.0
Silphidae (A)	2	0.4	0.1	1.0
Tenebrionidae (A)	5	1.1	0.4	2.5
Undetermined (A)	31	6.9	10.6	12.0
Dermaptera	9	2.0	1.1	4.5
Diptera (A)	72	16.1	26.2	32.5
Hemiptera (N, A)	21	4.7	5.7	9.0
Homoptera (A)	7	1.6	1.9	3.5
Hymenoptera				
Formicidae (A)	31	6.9	5.4	14.0
Undetermined (A)	17	3.8	2.1	8.5
Lepidoptera (A)	35	7.8	8.1	16.0
Neuroptera (A)	18	4.0	2.2	8.0
Orthoptera				
Acrididae (N, A)	15	3.3	2.9	7.0
Tettigoniidae (N, A)	10	2.2	0.9	5.0
Undetermined (N, A)	27	6.1	7.4	10.5
Total:	445			

DISCUSSION—*Hemidactylus turcicus* is found in significant numbers on the UT campus as well as throughout the Tampa Bay region. The densities reported here are lower than those reported by Selcer (1986) for *H. turcicus* on the campus of Pan American University in Texas (544–2210/ha). High densities appear to be common in other coastal urban areas as well, including New Orleans, Louisiana (Rose and Barbour, 1968), and Galveston and Corpus Christi, Texas (Davis, 1974; Selcer, 1986), confirming that this species has successfully established itself over a wide geographical range.

Any analysis of life history traits considers a number of parameters including age and size at maturity, number and size of offspring, longevity, sex ratios, and survivorship (Stearns, 1992; Punzo, 2000b). At this site, the reproductive season of *H. turcicus* begins in early April and lasts through early September. It attains sexual maturity during the spring following hatching, at about eight months of age. This is somewhat earlier than the age of 8.6 months reported for this gecko by Selcer (1986) at Edinburg, Texas. Data on populations of *H. turcicus* from Louisiana and other areas of Florida and Texas also showed that sexual maturity was attained in less than a year (King, 1958; Rose and Barbour, 1968; Meshaka, 1995). All of these studies indicate that *H. turcicus* represents an early maturing species.

A majority of the males collected at both UT sites (66%) were reproductively active from the second week of June through the third week of August. Testicular regression began in early August and continued through the middle of October. At Edinburg, Texas, males matured earlier with high percentages of reproductively active males observed from April 1 to September 1 (Selcer, 1986).

Hemidactylus turcicus is characterized by low fecundity with a fixed clutch size of two eggs. Members of the subfamily Gekkoninae typically produce fixed clutches with two eggs (Selcer, 1990). The data from this study indicated that there is sufficient time for females to produce up to three clutches/season. This is in agreement with the results reported by Selcer (1986) from Texas. In south central Florida, *H. turcicus* produced an average of 3 clutches but can produce up to five (Meshaka, 1995). The ratio of males to females did not deviate significantly from 1:1 at either study site on the UT campus. This is in agreement with sex ratios reported for this gecko at other locations (King, 1958; Selcer, 1986; Meshaka, 1995), although Rose and Barbour (1968) reported a sex ratio skewed toward females during the months of May (39 males: 50 females) and June (32: 54) in New Orleans, Louisiana.

Only a few geckos moved from the SH site to the KB site even though these two buildings were only 25 m apart. Selcer (1986) reported infrequent movement between metal buildings separated by a distance of only 6 m. Similar restricted movement patterns between buildings 9 m apart were reported by Rose and Barbour (1968). Using allozyme analyses, Trout and Schwaner (1994) showed that *H. turcicus* formed discrete subpopulations with few polymorphic loci and low genetic variation within breeding groups, providing further evidence for low levels of migration between populations in this lizard. It should be pointed out, however, that Rose and Barbour (1968) observed adult geckos on the walls of buildings while numerous juveniles were found on sidewalks at night. This suggests that territorial behavior by adults may influence population densities and force juveniles to disperse to other locations. Juveniles were not commonly found on the ground or on sidewalks between buildings at UT.

These geckos escape into wall crevices or dart under surface debris when approached. Although a number of vertebrates and arthropods were observed capturing geckos, the fact that *H. turcicus* is cryptic, nocturnal in its activity patterns, and arboreal, all serve to reduce contact with predators. These lizards also move their tails when threatened which could focus the attention of a potential predator to the tail which is easily autotomized allowing the gecko to escape.

The fact that *H. turcicus* is a generalist predator and consumes gastropods as well as a wide variety of arthropods, would contribute to its success.

It can choose from a wide variety of dietary items and still find food when some prey species become less available at different times of the year. Producing eggs with calcareous shells reduces evaporative water loss which also enhances the survivorship of this gecko, as well as allowing for the dispersal and survival of its eggs over long distances via human intervention.

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USF CHEMISTRY ACADEMIC GENEALOGIES

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ABSTRACT: *The academic genealogical trees of over 20 members of the Department of Chemistry at the University of South Florida were assembled. This is a listing of the faculty members, their doctoral institution and the year of the degree, followed by the same information for the person who directed their doctoral dissertations (and their degree institutions and date of degree), and so on back to (typically) one of three persons about 200 years ago: Jöns Jacob Berzelius, A. F. de Fourcroy, or C. L. Berthollet. Fewer than 10–12 generations separate most chemists from these three chemists. Methods and sources of information used in obtaining the information are given. The advantages are the assistance to a study of the history of chemistry, and a better appreciation of the past. The disadvantages are the challenges in determining the major advisor of a given individual, and problems obtaining information for persons in interdisciplinary areas, e.g., some biochemists, and some physical chemists, whose training was in physics. The value of this analysis is self-evident.*

DEVELOPMENT of academic genealogical trees or intellectual genealogies is a useful method for studying the history of a given profession. For each student, there should be a teacher who has exerted the greatest influence. For those with an earned doctorate, that person should be the doctoral advisor, and thus in academic genealogies, each person has a single parent, what Germans called "Der Doktervater," the doctor father.

Chemistry genealogies have been available for over sixty years. Virginia Bartow (1939) published one for the chemistry faculty at the University of Illinois-Urbana/Champaign. Graham (1948) published another for McMaster University in Hamilton, Ontario. Still others were published for Michigan State (McCarty, 1969), and University of Wisconsin–Madison (Rocke and Ihde, 1979), and a more recent one for the University of Illinois at Urbana-Champaign (Mainz,1994). Stone and Schweitzer (1976) published a useful general one.

One for the Department of Chemistry at the University of South Florida is available on our web page (*http://www.cas.usf.edu/chemistry/genealogy/genealogy.htm*), and some of the problems of assembling a departmental tree are described here, together with the advantages and disadvantages of the effort.

METHODS—Various sources were consulted, including Bartow (1939), Graham (1948), Rocke and Ihde (1979), McCarty (1969), Stone and Schweitzer (1976), and the helpful web page of the University of Illinois School of Chemical Sciences (Mainz, 1994) that shows the

Theodore Askounes Ashford
Chicago, 1936

M. Karasch
Chicago, 1919

J. F. Picard
E. T. H. Zurich, 1909

Richard Willstätter
Munich, 1894

Johan Fredrich Wilhelm Adolf von Baeyer
Berlin, 1858

Fredrick August Kekulé
Giessen, 1852

Justus von Liebig
Erlangen, 1822

J. L. Gay-Lussac
Paris, 1800

C. L. Berthollet
Paris,
1778

FIG. 1. Academic genealogy of Theodore Askounes Ashford, 1908–1987, USF faculty member 1959–1987.

intellectual genealogies prepared by Vera V. Mainz. In addition, *Dissertation Abstracts* was consulted through the USF Library Virtual Library system.

DISCUSSION—*Construction*—The first example of an academic chronology is given (Fig. 1) for Professor Theodore Askounes Ashford, who was the first full professor of Chemistry at USF, Director of the Division of Natural Sciences, and in 1971 was named Dean of the College of Natural Sciences. His academic genealogy is typical of those for organic chemists (Fig.1), and reflects his association with a noted organic chemist. Dean Ashford, however, chose to specialize in broader aspects of physical science and

W. Conard Fernelius
Stanford, 1928

F. Bergstrom
Stanford,1922

Edward Curtis Franklin
Johns-Hopkins, 1902

Ira Remsen
Göttingen, 1870

R. Fittig
Göttingen, 1858

F. Wöhler
Heidelberg, 1828

Jöns Jacob Berzelius
Uppsala, 1802

FIG. 2. Academic genealogy of W. Conard Fernelius, 1905–1986, USF faculty member, 1970–1975.

was the author of a textbook on the subject (Ashford, 1960). He received the Florida Award of the Florida Section of the American Chemical Society (ACS) in recognition of his activities as Chairman of the ACS Division of Chemical Education's Examination Committee from the 1940s until his death. The Committee, with the aid of subcommittees of volunteers, prepared and sold multiple-choice examinations for testing students in a variety of sub-disciplines of chemistry.

The second example of an academic genealogy is the one for Professor W. Conard Fernelius, USF's first Distinguished Professor of Chemistry (Fig. 2). "Fernie" was an inorganic chemist, who started his academic career at The Ohio State University as an instructor in the fall of 1928. He rose through the ranks and became a full professor in 1940. During World War II, he was on leave to work with the Manhattan District Project, engaged in war research with the Central Research Division of Monsanto in Dayton, Ohio, and finally became laboratory director. Later, he was appointed department chair, first at Syracuse University (1947–1949), later at Penn State (1949–1960). He was then associate director of research at Koppers until his first retirement in 1971, when he joined the faculty of USF. He was well known for his research with reactions in liquid ammonia and the chemistry of coordination compounds. He co-authored textbooks in general chemistry and inorganic chemistry. He also specialized in the nomenclature of inorganic chemistry (Block et al., 1990), and received an ACS award for his efforts in this area.

Commonly, a student's doctoral information can be used to locate the doctoral advisor, both in time and place. And this is made easier by searching *Dissertation Abstracts*, now available on line. This source has doctoral dissertation information dating from 1861. Unfortunately, of course, this source depends on information being provided by graduate institutions, and one encounters known gaps, as well as incorrect information. In addition, it is logical to take advantage of the research of others, as noted previously, if this is possible. Also, Bartow (1939), Rocke and Ihde (1949), and McCarty (1969) described many sources that they used.

Naturally, in some instances "grafting" was not feasible, so other approaches were used. Given the information from *Dissertation Abstracts, Chemical Abstracts* was searched for the doctoral student and a paper that matched the student's dissertation topic. This procedure would lead (in the 1920s to 1960s) to a paper in *Journal of the American Chemical Society,* hopefully with two authors, and the footnote, "Abstracted in part from a dissertation submitted in partial fulfillment of the requirements of Doctor of Philosophy . . ." Having three authors proved a complication in deciding who was the doctoral advisor. In this case a telephone call to the correct chemistry department was required to get the correct answer. Those telephone numbers are available in a publication (ACS, 1999). In one instance a librarian at the chemistry library at Columbia University was contacted to get the correct answer.

Other approaches were used for degrees awarded during the the early 1960s. One publication (cf. ACS, 1999) lists faculty members for each department and the names of their doctoral advisees and the titles of the dissertations. This approach has worked given the directories that appear every two years, dating back to the early1960s.

Complications—Some complications arose in the search for advisors prior to 1920. After World War I, it was less easy for chemists to progress through academic ranks without a graduate degree, as Rocke and Ihde noted (1979). For example, a noted organic chemist, Howard J. Lucas had his graduate career interrupted at the University of Chicago by the death of his father in 1910, but he later taught at Caltech, and his student, William Young, was the research advisor of another prominent chemist, John Roberts, who was the research advisor of other organic chemists. Rocke and Ihde (1979) presumed that Lucas was influenced by Julius Stieglitz at Chicago because he was the most prominent, active chemist then on the faculty.

Some genealogies are a matter of personal selection, and one can find more than one version as a consequence. Mainz (1994), for example, is forthright in noting this situation on her web page. A decision about who was the advisor of a noted analytical chemist, and the academic grandfather of a colleague, was complicated by two answers: the official advisor and another faculty member that he felt very close to and regarded as his true advisor. Neither answer could be ignored. In the end, we ended with two trees.

There might have been a better solution: The "family" tree can split. A colleague, Joseph A. Stanko, noted that he had two advisors at the University of Illinois. His first advisor, Theron Standish Piper, died as a consequence of complications from a laboratory accident, then Theodore Brown assumed responsibility for him. Both chemists (Brown and Piper) had the same academic ancestor.

Patterns—Chemists tend to be academically derived from three persons: a Swedish chemist, Jöns Jacob Berzelius, and two French chemists, de Fourcroy and Berthollet. The names of their advisors typically are not listed because they were not chemists. Berzelius' teacher, for example, Afzelius was a phlogistonist, not a chemist. Berthollet and de Fourcroy were both associated with Lavoisier, in the 1780s, but Berthollet was more properly a student of P. J. Macquer, a phlogistonist, and de Fourcroy was a student of J. B. M. Boucquet (1746–1780), who would not be termed a chemist by many today (Rocke and Ihde, 1979).

Other patterns were noted in addition to the change in educational demands on doctoral advisors. One is the change in doctoral education in this country. In the Nineteenth Century, it was common practice to earn a doctorate abroad. Justus von Liebig, an academic ancestor of many organic chemists, started a program of graduate education in the 1830s and later at Giessen. That program in many ways resembled the contemporary model: a focus on a central theme, use of students' fees to support the advising professor to be able to teach smaller numbers of students in a class or a program (Brock, 1992).

With the development of Yale's doctoral program in chemistry, the tendency to study and obtain doctorates in Chemistry abroad, diminished. For the academic descendants of Wisconsin chemists, William Albert Noyes ("Daddy Noyes") obtained the first American doctorate (Hopkins, 1882); Horace Wells was the first to obtain all of his training in the United States (Yale, 1878); and George Gibson was the last American chemist go abroad for his doctorate (Breslau, 1911), according to Rocke and Ihde (1979).

Another pattern should be noted. The "tree" that is shown (Fig. 1), was constructed that way for convenience. Some departmental genealogies look more like bushes than trees. This was done deliberately to show the relationships between faculty members. This is the pattern that was created for Illinois chemists (Bartow, 1939), for Badger genealogy (Rocke and Ihde, 1979), for the University of Illinois at Urbana-Champaign (Mainz, 1994), and for Emory chemists and Michigan State chemists (McCarty, 1969) that

I have seen. The "bush" pattern is a better approach, but more challenging, and requires more upkeep, as faculty come and go in a department.

Eurocentrist focus—The patterns that have been described tend to focus on those faculty who obtained their education in the United States. As we favor diversity, the range of doctoral institutions increases and the complexity of the effort increases. When exposed to English-educated colleagues, I found the pattern noted above also applied to English chemists, i.e., study abroad, first in France, later in Germany, many with Liebig.

Later, generations of Australian chemists would earn their doctorates in England, then return to Australia. This was a necessary practice because of the absence of post-graduate research opportunities in Australia. But it was a practice that continued even after the introduction of the Ph.D. in Australia and New Zealand in 1946 and 1948, respectively (Brock, 1992). The practice was stimulated by the availability of Rhodes Scholarships and free ship travel, of course, but there must been other reasons as well. Progress was rapid. John Earl was the first native-born Australian to hold a Chair of Chemistry (at Sydney), but 30 years later, Australians were awarded Chairs abroad, and in 1975 John Cornforth became the first Australian chemist to win the Nobel prize (Brock, 1992).

Advantages—It is interesting to learn more about academic ancestors: Berzelius, Berthollet, and de Fourcroy among others, and construction of academic genealogies has encouraged me and, hopefully others, to do this.

Jöns Jacob Berzelius, (1779–1848), a Swedish chemist, was a key force in promoting Dalton's atomic theory, is credited with discovering several elements, and making pioneering contributions to electrochemistry and chemical analysis (Russell, 1998). His personal life is also interesting. He was orphaned, had a bleak childhood, and for much of his life was a forlorn and lonely figure, highly regarded by colleagues and the monarchy. When he was 56, he married a woman who was 32 years younger; as a wedding gift, he was granted a Barony by the king (Russell, 1998). His recognition as a chemist was lasting. Russell (1998) describes another aspect, that after Berzelius' death, his widow continued to socialize and at a dinner was asked in a patronizing way what her husband did, and her interesting reply was, "Well, he's a statue in Berzeli Park."

Claude Louis Berthollet (1748–1822), a professor in Paris, led a full interesting life, both in the lab and outside (Partington, 1960). He was chosen to be one of the savants that accompanied Napoleon Bonaparte on the ill-fated Egyptian Campaign (1798). Within a month of arrival, Napoleon, his army, and the group of savants were stranded because the British fleet under Admiral Nelson destroyed the entire French fleet at Aboukir (Foreman and Phillips, 1999). The savants had time to look around and investigate and Berthollet discovered a "reverse reaction" in a estuarine environment: Calcium carbonate had reacted with salt to form trona (sodium carbonate). This was the reverse of the usual reaction of calcium chloride and sodium carbonate to produce calcium carbonate and sodium chloride. This discovery, in my view, ultimately led to the concept of chemical equilibrium, though more credit needs to be given to Guldberg and Waage (cf. Weeks and Leicester, 1968).

Antoine Francois de Fourcroy (1755–1809) was professor (after Macquer) at the Jardin des Plantes, and would later occupy other official positions (Partington, 1960). His research was largely in physiological chemistry ("animal chemistry"), mostly in collaboration with Louis Nicolas Vauquelin (1763–1829), discover of chromium compounds, chromium and beryllium. Also, de Fourcroy was said to be an excellent writer and lecturer, and is credited with popularizing antiphlogiston views of Lavoisier (Partington, 1960).

Limitations—Deciding on the major advisor can be a major limitation, and, as McCarty (1969) properly noted, it is not possible to show the persons a given chemist may have studied with or been significantly influenced by without truly complicating the genealogic tree. In the Nineteenth Century, chemists like Liebig or Kekulé commonly visited more than one university, worked with more than one person, then finally submitted a dissertation to one university in order to receive a degree.

Justus von Liebig is an interesting case in point (Brock, 1992). His Doktorvater was Karl Wilhelm Kastner (1783–1857), who was at the University of Bonn. Kastner obtained chemicals from Liebig's father, who ran a Drogerie, in Darmstadt. This store supplied paints, varnishes and household chemicals that Liebig helped prepare in an adjacent workshop. Kastner accepted Liebig as a personal assistant, trained him in chemistry, allowed him to attend his lectures, even without the proper certification. Kastner also arranged for a travel grant to Paris, and even arranged for him to obtain essentially an honorary degree in absentia from Erlangen (without presenting a dissertation). In Paris, he studied with Gay-Lussac and Thenard and learned much. He also made a valuable social contact with Alexander von Humbolt, Prussian Ambassador to France, who strongly recommended him, for his first academic position (Giessen, 1824). Later, Liebig was "rude about Kastner's competence as a chemist and decidedly ungracious towards him," according to Brock (1992).

Obviously, one might think that Kastner was Liebig's major mentor. But every genealogic tree credits Gay-Lussac (Bartow, 1939; Graham, 1948; Rocke and Ihde, 1949; McCarty, 1969). It may be due to a common source: Virginia Bartow cited Moore (1931) as a source of information on Liebig. It may be a matter of judgment: Rocke and Ihde (1949) noted that Kastner was Liebig's Doktorvater, but added "he [Liebig] learned much more chemistry from Gay-Lussac and Thenard." Liebig's enthusiasm impressed Gay-Lussac, who allowed him to work by his side in his laboratory, an uncommon occurrence, because Gay-Lussac's university teaching did not involve much personal contact with students, according to Crosland (2000). Together they collaborated on a memoir ("Analysis of Silver Fulminate", published in *Annales de chemie et de physique*) during the winter of 1823–24, a collaboration Liebig would later describe as a turning point in his life (Crosland, 2000).

Liebig had his impact as a teacher. The Deutsches Museum in Munich has a genealogical tree showing Justus von Liebig, his students, and their students through five professional generations, a tree that included 33 Nobel prize winners (Stone and Schweitzer, 1976). There are limitations other than decisions and opinions in academic genealogies. It should be evident that the academic tree really presents only the immediate ancestors. In addition, the examples noted have been for chemists, though one colleague traces an ancestry back through connections with physicists. It would be interesting to follow the academic trees for other disciplines—Biology, Botany, Geology, Physics, and Zoology. In addition, the "trees" of some colleagues in the Department of Chemistry at USF represent the challenges of diversity. The academic genealogies of some colleagues who earned their doctorates in Spain, India, and Russia still prove challenging, but hopefully time remains to pursue this intellectually stimulating and interesting academic pursuit.

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QUARTERLY JOURNAL OF THE FLORIDA ACADEMY OF SCIENCES

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Biological Sciences

COVER AND SPECIES RICHNESS OF FIRE-INFLUENCED PINE AND WET PRAIRIE HABITATS IN SOUTHWEST FLORIDA

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Abstract: *Habitat management, monitoring, and restoration efforts can benefit from regional information on plant community composition and structure from representative native habitats. We developed plant species lists and calculated percent cover and frequency averaged over multiple sampling events for forbs, graminoids, and shrubby vegetation in fire-managed slash pine (*Pinus elliottii *var.* densa*) and wet prairie habitats in southwest Florida. Slash pine habitats included 185 species of forbs, 74 species of graminoids, and 34 species of shrubs. Mean percent cover in slash pine habitat was dominated by shrubs (67%), followed by forbs (47%) and graminoids (28%). Species richness in wet prairie habitats included 135 species of forbs, 64 species of graminoids, and 18 species of shrubs. Mean percent cover in wet prairie habitat was dominated by graminoids (81%), followed by forbs (41%) and shrubs (9%).*

Southwest Florida has experienced rapid expansion of the citrus industry and explosive population growth during the last two decades (Mulkey et al., 1997; Mazzotti et al., 1992). Consequently, the rapid rate at which native habitats have been converted to other uses warrants close attention to management of remaining natural areas. Also, restoration of degraded natural areas due to altered hydrology, suppression of fire, invasion of exotic species, or modification of land use and resource extraction practices has become increasingly important in south Florida as native habitats continue to disappear at a rapid rate (Noss et al., 1995). The importance of restoration efforts in south Florida is substantiated by the enormous investment in the South Florida Ecosystem Restoration Initiative, of which the Central and

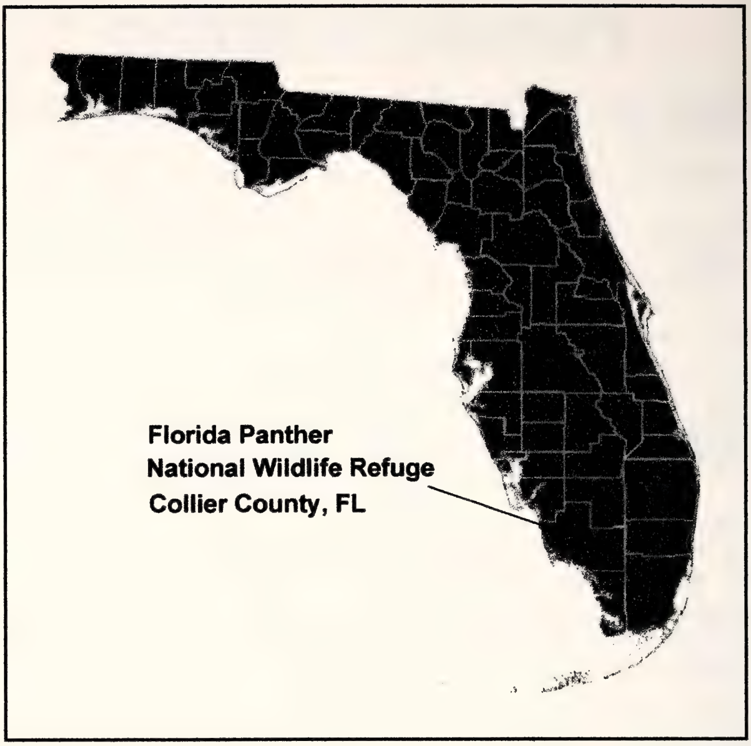

FIG. 1. Location of study area, Florida Panther National Wildlife Refuge, Collier County, Florida.

Southern Florida Restudy is estimated to cost $7.8 billion over the next 20 years (U.S. Fish and Wildlife Service, 1999).

Restoration activities attempt to return degraded habitats to their "natural state," although what represents a natural state is difficult to quantify (Meffe and Carroll, 1997). Baseline information on plant and wildlife communities from habitats with management programs that maintain historical disturbance processes can provide general guidelines for restoration goals. Our objectives were to develop plant species lists and relative abundance rankings for forbs, graminoids, and shrubby vegetation in fire-managed slash pine and wet prairie habitats in southwest Florida.

STUDY AREA—We conducted this study on the 10,636 ha Florida Panther National Wildlife Refuge (FPNWR) in Collier County, Florida (Fig. 1). The FPNWR occurs within the Big Cypress Basin, which encompasses over 3,800 km^2 of subtropical, wetland-dominated habitats in southwest Florida. The refuge ranges 3–5 m above sea level and major habitats include hardwood hammock, mixed hardwood swamp, cypress (*Taxodium ascendens, T. distichum*) swamps, slash pine flatwoods, sloughs, and wet prairies (Florida

Panther NWR, unpublished data). Our study concentrated on pine flatwoods and wet prairie habitats, which constitute approximately 22% and 4% of total refuge area, respectively.

Both pine flatwoods and wet prairie habitats are characterized by shallow sandy soils over limestone cap rock (Duever et al., 1986; Liudahl et al., 1998). Annual rainfall at FPNWR averages 22 cm/yr, >71% of which occurs during May–October (FPNWR unpublished data). Sheet flow of surface water is characteristic of this region during the June–September rainy season. Drier conditions persist during the south Florida dry season, which typically extends from November–April.

Prescribed burning is the primary management practice used to control succession and maintain native plant communities on the FPNWR. The FPNWR is subdivided into 53 fire management units (FMU) that range in size from 103–451 ha ($\bar{x}$ = 201 ha) and that are on a 4-yr prescribed fire rotation.

METHODS—We conducted growing season prescribed fire in 3 FMU during May 1996 and 3 FMU during May 1997, and dormant season prescribed fire in 3 FMU during January 1997 and 3 FMU during January 1998. We used flanking fires to the greatest extent possible during fire treatments. Fuel loads were not quantified.

We established three permanent sampling sites in both pine and wet prairie habitats within each FMU and established three permanent 50-m transects at each sampling site. Transects were distributed ≥15 m apart in a stratified, random manner (Pieper, 1978). We used 0.5-m^2 (100 × 50-cm) quadrats at 10 m intervals along transects to quantify each species by frequency and cover class (Daubenmire, 1959), with cover class being converted to percent cover (Pieper, 1978). Each quadrat was sampled pre-fire and 3-, 6-, and 12-mo. post-fire. This design resulted in a sampling effort of 2,560 quadrats for each habitat over a 2-yr period. We identified all forbs, graminoids, and shrubs that occurred within sampling quadrats to species level to the greatest extent possible. Species were identified following the nomenclature of Wunderlin (1998), with the exception of south Florida bluestem (*Schizachyrium rhizomatum*) (Tobe et al., 1998), which is classified by Wunderlin as gulf bluestem (*S. scoparium*).. Voucher specimens for most species are available at the FPNWR herbarium (Main and Barry, 1998).

RESULTS—We recorded 294 species of forbs, graminoids, and shrubby vegetation in pine habitat at FPNWR (Appendix 1). Species richness of the understory was dominated by forbs with 186 species (63%), followed by graminoids with 74 species (25%), and shrubs had the lowest species richness with 34 species (12%). Percent cover in pine habitats was dominated by shrubs (67%), followed by forbs (47%) and graminoids (28%). The majority of species made small contributions to total mean cover. Among forbs, 160 (86%) of the species constituted <0.5% mean cover. Graminoids had 61 species (82%) and shrubs had 23 species (68%) that contributed <0.5% total mean cover. Sabal palm (*Sabal palmetto*; 27%) and saw palmetto (*Serenoa repens*; 22%) were the two most dominant species in pine habitat by mean percent cover (Appendix 1). Gulfdune paspalum (*Paspalum monostachyum*; 6%), little blue maidencane (*Amphicarpum muhlenbergianum*; 3%), and saw grass (*Cladium jamaicense*; 3%) were dominant graminoids and chocolate weed (*Melochia spicata*; 5%), rosy camphorweed (*Pluchea rosea*; 3%), and wild sensitive plant (*Chamaecrista nicitans*; 2%) were dominant forbs in pine habitat. Wet prairie had lower species richness than pine habitat at FPNWR. We recorded 216 species that included 134 species of forbs, 64 species of graminoids, and 18 species of shrubs in sample plots in wet prairie habitats on the FPNWR (Appendix 1). Species richness followed a similar pattern in wet prairies as in pine habitat, with forbs constituting the greatest percentage of species (62%), followed by graminoids (30%) and shrubs (8%). In contrast to pine habitat, however, the dominant plants by mean percent cover averaged over all sampling events were graminoids (81%), followed by forbs (41%) and shrubs (9%). Gulfdune paspalum (22%), saw grass (12%), muhly (*Muhlenbergia capillaris*; 8%), and south Florida bluestem (7%) were dominant graminoids by mean percent cover (Appendix 1). Wax myrtle (*Myrica cerifera*; 4%) and cabbage palm (3%) were dominant shrubs. Rosy camphorweed (4%) and Asiatic pennywort (*Centella asiatica*; 4%) were dominant forbs at wet prairie sites (Appendix 1). As in pine habitat, the majority of species made small contributions to total mean cover with 111 species (82%) of forbs, 44 species (69%) of graminoids, and 15 species (68%) of shrubs contributing <0.5 % mean cover (Appendix 1).

DISCUSSION—The species diversity of plant communities in pine and wet prairie habitats in south Florida is a function of seasonal hydrology and periodic disturbance by fire (Abrahamson and Hartnett, 1990; Kushlan, 1990). Changes in plant community composition may occur immediately following fire because many species in fire-prone habitats in south Florida possess evolutionary adaptations that enable them to exploit areas immediately after fire (Snyder, 1986). Likewise, many plants in south Florida have evolved the ability to recover rapidly after fire, returning community structure to pre-fire conditions (Snyder, 1986). Consequently, sampling during different phases of post-fire recovery can provide a broad view of the role of dominant species and growth forms in a fire-managed landscape.

Although fire influenced species diversity of forbs, graminoids, and shrubs differently and season of fire influenced community structure during post-fire recovery, overall species richness recovered to pre-fire level following the passage of a single growing season regardless of season of fire (Main et al., 2000). Consequently, regional vascular plant species lists provide valuable baseline information that may be used to identify broad ecological changes in habitat structure, such as described by Austin and coworkers (1990) at the Florida Atlantic University in Boca Raton, Florida. In south Florida, regional species lists have been compiled from various locations, including the Big Cypress National Preserve (Black and Black, 1980), Everglades National Park (Avery and Loope, 1983), Fakahatchee Strand State Preserve (Austin et al., 1990), and FPNWR (Main and Barry, 1998). Although lists of species are valuable, documenting more subtle changes in plant communities due to fire suppression and other reasons requires quantification of community structure, such as provided by measures of cover and frequency (Abrahamson, 1984; Moore et al., 1982; Platt et al., 1989). This is particularly true when objectives include comparing habitat restoration efforts with healthy native communities considered representative of a region. For example, the Florida Division of Forestry recently acquired the 23,600-ha Picayune Strand State Forest (PSSF), formerly known as Southern Golden Gate Estates, in southwest Florida's Collier County. Habitats within PSSF are highly degraded by altered hydrology, suppressed fire regimes, and invasion of exotic plants largely due to construction of interstate I-75 (Alligator Alley) along PSSF's northern boundary and extensive construction of platted roads and canals for subdivision-type housing throughout the property (Polizos, 1999).

By quantifying percent cover and frequency data for herbaceous and shrubby vegetation in fire-managed habitat on the FPNWR, we provide a general sense of plant community composition and structure for pine and wet prairie habitats in southwest Florida. Although it is important to recognize that no two areas or sampling events will provide identical results, development of restoration objectives and monitoring restoration progress at PSSF and other areas can benefit from regional information on plant community composition and structure in representative native habitats.

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APPENDIX 1. Total mean percent cover and frequency by species constituting ≥0.5% of total cover in pine and wet prairie habitat averaged over all pre- and post-fire sampling events.

Growth form	Common name	Scientific name	Pine habitat Cover mean (%)	Pine habitat Frequency mean (%)	Wet prairie habitat Cover mean (%)	Wet prairie habitat Frequency mean (%)
Forb	Chocolate weed	*Melochia spicata*	5.02	37.00	1.22	10.75
	Rosy camphorweed	*Pluchea rosea*	2.99	38.00	4.04	40.75
	Wild sensitive plant	*Chamaecrista nictitans*	1.92	24.25	0.02	0.51
	Wild petunia	*Ruellia caroliniensis*	1.75	26.75	1.74	24.25
	Poison ivy	*Toxicodendron radicans*	1.67	35.75	0.03	1.10
	Asiatic pennywort	*Centella asiatica*	1.50	33.25	3.49	86.75
	Swamp fern	*Blechnum serrulatum*	1.42	10.00	0.01	0.31
	Snow squarestem	*Melanthera nivea*	1.35	15.50	0.23	3.60
	Muscadine grape	*Vitis rotundifolia*	1.35	15.75	—	—
	Bracken fern	*Pteridium aquilinum*	1.23	15.50	—	—
	Southern dewberry	*Rubus trivialis*	1.12	26.50	0.01	0.13
	Small-fruit seedbox	*Ludwigia microcarpa*	1.05	26.25	2.65	65.00
	Elephant's foot	*Elephantopus elatus*	1.05	14.00	0.01	0.50
	Musky mint	*Hyptis alata*	1.04	21.50	3.37	66.50
	Saw greenbrier	*Smilax bona-nox*	1.04	20.25	0.01	0.13
	Caesar-weed	*Urena lobata*	1.02	9.50	—	—
	Semaphore thorough-wort	*Eupatorium mikanioides*	0.84	15.00	0.10	3.25
	Prostrate rattle-box	*Crotalaria rotundifolia*	0.83	17.25	0.02	0.63
	Rhynchosia	*Rhynchosia minima*	0.76	7.09	—	—
	Elytraria	*Elytraria caroliniensis*	0.71	22.50	1.60	51.50
	Baldwin's coyote-thistle	*Eryngium baldwinii*	0.69	21.25	0.65	20.25
	St. John's-wort	*Hypericum brachyphyllum*	0.66	12.00	0.80	12.50
	Queen's-delight	*Stillingia sylvatica*	0.63	8.75	0.30	5.00
	Climbing hempvine	*Mikania scandens*	0.57	13.50	1.96	35.75
	Beauty-bush	*Callicarpa americana*	0.57	7.50	—	—
	Spermacoce	*Spermacoce assurgens*	0.51	11.75	1.57	15.00
	Saltmarsh morning-glory	*Ipomoea sagittata*	0.50	12.50	1.30	36.75

APPENDIX 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Forb	Pepper-vine	*Ampelopsis arborea*	0.45	7.75	0.23	3.25
	Greenbrier	*Smilax auriculata*	0.44	9.25	—	—
	Yellow thistle	*Cirsium horridulum*	0.40	8.25	0.73	14.50
	Loosestrife	*Lythrum alatum*	0.39	4.50	0.12	2.30
	Dyschoriste	*Dyschoriste oblongifolia*	0.39	12.00	0.01	0.30
	Rattlesnake-master	*Eryngium yuccifolium*	0.37	2.50	0.02	0.50
	Pineland heliotrope	*Heliotropium polyphyllum*	0.35	11.00	0.63	19.50
	Three-seeded mercury	*Acalypha graciliens*	0.35	9.84	0.01	0.31
	Florida prairie-clover	*Dalea carthagenensis*	0.34	3.59	—	—
	Buttonweed	*Diodia virginiana*	0.32	9.75	0.31	10.00
	Fennel	*Eupatorium leptophyllum*	0.30	7.00	1.03	17.75
	Candyroot	*Polygala grandiflora*	0.30	10.25	0.33	10.50
	White crownbeard	*Verbesina virginica*	0.29	1.30	—	—
	Unknown aster	*Unknown Asteraceae*	0.28	9.00	0.28	9.25
	Fine-stem lovevine	*Cassytha filiformis*	0.27	7.32	0.25	4.88
	Carpetweed	*Phyla nodiflora*	0.26	7.25	1.17	21.75
	Pineland dyschoriste	*Dyschoriste angusta*	0.25	7.75	0.52	16.75
	Black-eyed susan	*Rudbeckia hirta*	0.25	6.75	0.07	2.60
	Unknown aster	*Unknown Asteraceae*	0.24	7.75	0.13	2.75
	Miterwort	*Mitreola petiolata*	0.23	7.75	0.92	24.25
	Mermaid-weed	*Proserpinaca pectinata*	0.23	5.75	0.73	20.50
	Corymb false-fiddle-leaf	*Hydrolea corymbosa*	0.21	6.50	0.54	13.00
	Aster	*Aster dumosus*	0.21	6.00	0.11	3.50
	Galactia	*Galactia volubilis*	0.21	6.55	0.01	0.25
	Virginia creeper	*Parthenocissus quinquefolia*	0.21	4.50	—	—
	St. John's wort	*Hypericum hypericoides*	0.20	5.50	0.05	1.50
	Ground cherry	*Physalis walteri*	0.16	5.25	0.04	1.25
	Ocean blue morning-glory	*Ipomoea indica*	0.16	2.75	—	—

Appendix 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Forb	Goldenrod	*Solidago fistulosa*	0.15	3.00	0.01	0.31
	Saltmarsh-mallow	*Kosteletzkya virginica*	0.15	4.00	—	—
	Cross-leaf milkwort	*Polygala cruciata*	0.14	3.16	0.01	0.25
	Beggar's ticks	*Desmodium marilandicum*	0.14	3.00	—	—
	Silky false-morning-glory	*Evolvulus sericeus*	0.13	4.25	0.04	1.55
	Water willow	*Justicia angusta*	0.12	4.00	0.26	8.00
	Maiden fern	*Thelypteris kunthii*	0.11	1.75	0.11	0.38
	Anemia	*Anemia adiantifolia*	0.11	1.50	—	—
	Elliott's milkpea	*Galactia elliottii*	0.11	3.25	—	—
	Florida bellflower	*Campanula floridana*	0.11	3.50	—	—
	Yellow-top flaveria	*Flaveria linearis*	0.10	2.00	0.75	13.00
	Yellow-star grass	*Hypoxis juncea*	0.10	3.05	0.17	5.50
	Dog fennel	*Eupatorium capillifolium*	0.10	2.50	0.15	0.88
	Goldenrod	*Solidago tortifolia*	0.10	3.00	0.01	0.06
	Golden aster	*Pityopsis graminifolia*	0.10	2.75	—	—
	Pineland golden trumpet	*Angadenia berteri*	0.10	1.36	—	—
	Tick-treefoil	*Desmodium paniculatum*	0.10	1.50	—	—
	Leavenworth's tickseed	*Coreopsis leavenworthii*	0.09	2.75	0.07	2.25
	Carolina leaf-flower	*Phyllanthus caroliniensis*	0.08	2.75	0.39	12.75
	Yellow flax	*Linum medium*	0.08	2.80	0.11	3.56
	Spurge	*Euphorbia polyphylla*	0.08	2.50	0.02	0.75
	Blackroot	*Pterocaulon pycnostachyum*	0.08	1.25	—	—
	St. John's-wort	*Hypericum cistifolium*	0.08	1.75	—	—
	Mistflower	*Conoclinium coelestinum*	0.07	2.13	0.43	9.50
	Purple mecardonia	*Mecardonia acuminata*	0.07	1.25	0.22	6.25
	Creeping woodsorrel	*Oxalis corniculata*	0.07	2.32	0.19	5.25
	Yellow-eyed grass	*Xyris* spp.	0.07	2.25	0.09	2.75
	Vetch	*Vicia acutifolia*	0.06	2.07	0.08	2.78

Appendix 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Forb	American germander	*Teucrium canadense*	0.06	0.75	0.04	0.38
	Alabama supple-jack	*Berchemia scandens*	0.06	1.25	0.03	0.91
	Beggar's tick	*Desmodium incanum*	0.06	0.82	—	—
	Calusa grape	*Vitis shuttleworthii*	0.06	0.41	—	—
	Pennyroyal	*Piloblephis rigida*	0.06	1.32	—	—
	Toothpetal false rein orchid	*Habenaria floribunda*	0.06	2.16	—	—
	Water pennywort	*Hydrocotyle umbellata*	0.05	1.55	0.09	1.57
	Florida ironweed	*Vernonia blodgettii*	0.05	1.75	0.06	1.62
	Thoroughwort	*Eupatorium mohrii*	0.05	1.25	0.01	0.25
	Waxweed	*Cuphea carthagenensis*	0.05	1.55	0.01	0.25
	West indian drymary	*Drymaria cordata*	0.05	1.09	0.00	0.05
	Woolly sunbonnets	*Chaptalia tomentosa*	0.05	1.50	—	—
	Water-dropwort	*Oxypolis filiformis*	0.04	1.07	0.71	15.50
	Sunnybell	*Schoenolirion albiflorum*	0.04	1.32	0.18	3.75
	Hedge-hyssop	*Gratiola ramosa*	0.04	1.50	0.10	3.50
	Marsh caperonia	*Caperonia palustris*	0.04	1.25	0.09	2.05
	Piriqueta	*Piriqueta caroliniana*	0.04	1.25	0.08	2.55
	Willow-leaf golden-rod	*Solidago stricta*	0.04	1.30	0.06	2.00
	Garber's gayfeather	*Liatris garberi*	0.04	1.05	0.00	0.06
	Goldenrod	*Solidago odora*	0.04	1.05	—	—
	Low hairy ground-cherry	*Physalis pubescens*	0.04	1.05	—	—
	Vanilla plant	*Carphephorus odoratissimus*	0.04	0.75	—	—
	Glades lobelia	*Lobelia glandulosa*	0.03	0.86	0.75	22.50
	Southern fleabane	*Erigeron quercifolius*	0.03	1.07	0.34	9.75
	Yellow colic-root	*Aletris lutea*	0.03	0.57	0.07	2.25
	Ravenel's pipewort	*Eriocaulon ravenelii*	0.03	0.57	0.05	1.61
	Aster	*Aster adnatus*	0.03	1.00	0.01	0.31
	Flat-topped goldenrod	*Euthamia caroliniana*	0.03	0.91	0.01	0.28

APPENDIX 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Forb	St. John's-wort	*Hypericum tetrapetalum*	0.03	0.88	0.01	0.25
	Long-leaf violet	*Viola lanceolata*	0.03	0.82	—	—
	Meadow beauty	*Rhexia mariana*	0.03	1.05	—	—
	Unknown forb	*Unknown Eriocaulaceae*	0.03	0.07	—	—
	Creeping spotflower	*Acmella oppositifolia*	0.02	0.59	0.20	6.00
	Red ludwigia	*Ludwigia repens*	0.02	0.50	0.16	4.25
	Pink ammannia	*Ammannia latifolia*	0.02	0.55	0.06	1.53
	Spermacoce	*Spermacoce prostrata*	0.02	0.63	0.06	1.75
	White vine	*Sarcostemma clausum*	0.02	0.38	0.02	1.00
	Sea-side goldenrod	*Solidago sempervirens*	0.02	0.61	0.01	0.14
	Pine-hyacinth	*Clematis baldwinii*	0.02	0.57	0.00	0.03
	Creeping cucumber	*Melothria pendula*	0.02	0.61	—	—
	Galactia	*Galactia regularis*	0.02	0.82	—	—
	Hedyotis	*Hedyotis uniflora*	0.02	0.50	—	—
	Hoary-pea	*Tephrosia spicata*	0.02	0.75	—	—
	Rayless goldenrod	*Bigelowia nudata*	0.02	0.75	—	—
	Summer grape	*Vitis aestivalis*	0.02	0.57	—	—
	Pointed blue-eye-grass	*Sisyrinchium angustifolium*	0.01	0.32	0.29	9.25
	Corkwood	*Stillingia aquatica*	0.01	0.11	0.19	4.00
	Coast water pimpernel	*Samolus ebracteatus*	0.01	0.25	0.13	3.25
	Stenandrium	*Stenandrium dulce*	0.01	0.25	0.13	4.50
	Water-hyssop	*Bacopa caroliniana*	0.01	0.16	0.09	1.56
	Southeastern sneezeweed	*Helenium pinnatifidum*	0.01	0.25	0.06	2.25
	Red-root	*Lachnanthes caroliana*	0.01	0.11	0.04	1.31
	Purple false dragon-head	*Physostegia purpurea*	0.01	0.50	0.01	0.31
	Saltmarsh rose-gentian	*Sabatia stellaris*	0.01	0.25	0.01	0.50
	Spurge	*Chamaesyce hyssopifolia*	0.01	0.25	0.01	0.30
	Mild water-pepper	*Polygonum hydropiperoides*	0.01	0.25	0.00	0.03

APPENDIX 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
	Cut-leaf ground-cherry	*Physalis angulata*	0.01	0.11	0.00	0.06
	Elliott's aster	*Aster elliottii*	0.01	0.25	0.00	0.06
	Marsh St. John's-wort	*Triadenum virginicum*	0.01	0.50	0.00	0.05
	Stiff marsh bedstraw	*Galium tinctorium*	0.01	0.25	0.00	0.10
	Bay lobelia	*Lobelia feayana*	0.01	0.41	—	—
	Bog-buttons	*Lachnocaulon anceps*	0.01	0.25	—	—
	Butterfly-pea	*Centrosema virginianum*	0.01	0.32	—	—
	Chain fern	*Woodwardia virginica*	0.01	0.16	—	—
	Common sowthistle	*Sonchus oleraceus*	0.01	0.32	—	—
	Fireweed	*Erechtites hieracifolia*	0.01	0.37	—	—
	Florida keys hempweed	*Mikania cordifolia*	0.01	0.32	—	—
	Greenbrier	*Smilax laurifolia*	0.01	0.09	—	—
	Hawkweed	*Hieracium megacephalon*	0.01	0.50	—	—
	Ludwigia	*Ludwigia virgata*	0.01	0.25	—	—
	Partridge pea	*Chamaecrista fasciculata*	0.01	0.25	—	—
	Piedmont sumpweed	*Iva microcephala*	0.01	0.25	—	—
	Pineland croton	*Croton linearis*	0.01	0.25	—	—
	Sand blackberry	*Rubus cuneifolius*	0.01	0.25	—	—
	Sand dune spurge	*Chamaesyce bombensis*	0.01	0.32	—	—
	Stinking camphor-weed	*Pluchea foetida*	0.01	0.05	—	—
	Sweet goldenrod	*Solidago odora*	0.01	0.25	—	—
	Tread softly	*Cnidoscolus stimulosus*	0.01	0.32	—	—
	Unknown forb	*Unknown legume*	0.01	0.32	—	—
	White lobelia	*Lobelia paludosa*	0.01	0.25	—	—
	Unknown forb	*Unknown Acanthaceae*	0.00	0.03	—	—
	Beach false-foxglove	*Agalinis fasciculata*	0.00	0.05	0.05	1.05
	Carter's flax	*Linum carteri*	0.00	0.07	0.05	1.55
	Annual marsh aster	*Aster subulatus*	0.00	0.05	0.03	1.06

Appendix 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Forb	Arrowhead	*Sagittaria graminea*	0.00	0.07	0.02	0.81
	Baldwin's milkwort	*Polygala balduinii*	0.00	0.07	0.02	0.56
	Narrow-leaf milkweed	*Asclepias lanceolata*	0.00	0.07	0.02	0.55
	Saltmarsh aster	*Aster tenuifolius*	0.00	0.05	0.01	0.25
	Savannah milkweed	*Asclepias pedicellata*	0.00	0.07	0.01	0.25
	Small-head boltonia	*Boltonia diffusa*	0.00	0.07	0.01	0.10
	Cudweed	*Gnaphalium falcatum*	0.00	0.05	0.00	0.05
	Malayan false-pimpernel	*Lindernia crustacea*	0.00	0.10	0.00	0.05
	Bog-hemp, false-nettle	*Boehmeria cylindrica*	0.00	0.11	—	—
	Dayflower	*Commelina diffusa*	0.00	0.07	—	—
	Dotted smartweed	*Polygonum punctatum*	0.00	0.07	—	—
	Early whitetop fleabane	*Erigeron vernus*	0.00	0.07	—	—
	Pellitory	*Parietaria praetermissa*	0.00	0.07	—	—
	Pineland sunflower	*Helianthus radula*	0.00	0.07	—	—
	Pink sundew	*Drosera capillaris*	0.00	0.07	—	—
	Rhynchosia	*Rhynchosia reniformis*	0.00	0.05	—	—
	Three-flower tick-trefoil	*Desmodium triflorum*	0.00	0.07	—	—
	West indian meadow-beauty	*Rhexia cubensis*	0.00	0.07	—	—
	Wild coco	*Eulophia alta*	0.00	0.07	—	—
	Unknown Ludwigia	*Ludwigia spp.*	—	—	0.10	1.38
	Blueheart	*Buchnera americana*	—	—	0.07	2.35
	Pipewort	*Eriocaulon compressum*	—	—	0.05	1.10
	Spiked gayfeather	*Liatris spicata*	—	—	0.04	1.00
	Elliott's golden-rod	*Solidago latissimifolia*	—	—	0.03	0.25
	Horned bladderwort	*Utricularia cornuta*	—	—	0.02	0.31
	Lavender bladderwort	*Utricularia resupinata*	—	—	0.02	0.31
	Small butterwort	*Pinguicula pumila*	—	—	0.02	0.80
	Aquatic milkweed	*Asclepias perennis*	—	—	0.01	0.31

Appendix 1. Continued.

Growth form	Common name	Scientific name	Pine habitat Cover mean (%)	Pine habitat Frequency mean (%)	Wet prairie habitat Cover mean (%)	Wet prairie habitat Frequency mean (%)
Forb	Bladderwort	*Utricularia juncea*	—	—	0.01	0.25
	Egg-leaf indian-plantain	*Arnoglossum ovatum*	—	—	0.01	0.31
	Hyssop	*Bacopa monnieri*	—	—	0.01	0.25
	Unknown Spiranthes	*Spiranthes spp.*	—	—	0.01	0.25
	Marsh pink	*Sabatia grandiflora*	—	—	0.00	0.03
	Purple ammannia	*Ammannia coccinea*	—	—	0.00	0.03
	Unknown Asclepias	*Asclepias spp.*	—	—	0.00	0.10
	Yellow-eyed grass	*Xyris elliottii*	—	—	0.00	0.06
Graminoid	Gulfdune paspalum	*Paspalum monostachyum*	5.88	43.25	21.95	82.00
	Little blue maidencane	*Amphicarpum muhlenbergianum*	2.80	38.75	2.01	25.00
	Saw-grass	*Cladium jamaicense*	2.79	26.50	11.74	53.75
	Florida false beardgrass	*Chrysopogon pauciflorus*	1.77	14.00	—	—
	Witchgrass	*Dichanthelium dichotomum*	1.59	15.00	1.54	36.00
	Low panicum	*Dichanthelium ovale*	1.18	25.25	0.40	9.00
	Muhly	*Muhlenbergia capillaris*	1.04	6.50	8.41	34.00
	White-top sedge	*Rhynchospora colorata*	0.91	24.00	3.00	68.75
	Sreading beaksedge	*Rhynchospora divergens*	0.88	17.75	5.85	51.75
	Needle-leaf witchgrass	*Dichanthelium aciculare*	0.80	13.00	1.91	21.50
	South florida bluestem	*Schizachyrium rhizomatum*	0.67	11.75	7.43	42.25
	Shaggy crabgrass	*Digitaria filiformis*	0.64	7.75	0.03	0.25
	Beaked panic grass	*Panicum anceps*	0.55	4.75	0.14	0.75
	Crimson bluestem	*Schizachyrium sanguineum*	0.36	2.84	0.01	0.25
	Saltmarsh fingergrass	*Eustachys glauca*	0.33	4.00	0.57	10.50
	Low panicum	*Dichanthelium ensifolium*	0.30	5.50	0.02	0.60
	Witchgrass	*Dichanthelium commutatum*	0.30	5.50	—	—
	Bushy bluestem	*Andropogon glomeratus*	0.27	5.50	0.30	5.25
	Nut-rush	*Scleria reticularis*	0.26	6.75	0.17	3.50
	Beaksedge	*Rhynchospora microcarpa*	0.23	5.75	2.34	47.25

APPENDIX 1. Continued.

Growth form	Common name	Scientific name	Pine habitat Cover mean (%)	Pine habitat Frequency mean (%)	Wet prairie habitat Cover mean (%)	Wet prairie habitat Frequency mean (%)
Graminoid	Knotroot foxtail	*Setaria parviflora*	0.23	3.75	0.73	11.50
	Globe beaksedge	*Rhynchospora globularis*	0.23	5.25	0.01	0.31
	Eastern gama grass	*Tripsacum dactyloides*	0.23	0.61	—	—
	Lovegrass	*Eragrostis elliottii*	0.22	2.25	1.66	27.50
	Unknown grass	*Unknown Cyperaceae*	0.22	6.75	0.05	1.06
	Lopsided indiangrass	*Sorghastrum secundum*	0.22	1.57	—	—
	Tall threeawn	*Aristida patula*	0.18	2.25	0.02	0.61
	Blodgett's paspalum	*Paspalum blodgettii*	0.17	3.75	0.26	2.00
	Blue paspalum	*Paspalum caespitosum*	0.17	3.25	0.03	1.06
	Brazilian satintail	*Imperata brasiliensis*	0.17	4.34	—	—
	Fragrant beaksedge	*Rhynchospora odorata*	0.14	2.50	2.14	17.00
	Gaping panicum	*Panicum hians*	0.14	3.75	0.04	1.00
	Switch grass	*Panicum virgatum*	0.12	1.50	0.02	0.25
	Broomsedge	*Andropogon virginicus*	0.11	2.00	0.06	0.75
	Woods grass	*Oplismenus hirtellus*	0.11	3.25	—	—
	Saltmarsh umbrella-sedge	*Fuirena breviseta*	0.10	2.50	0.70	17.50
	Redtop panicum	*Panicum rigidulum*	0.09	2.00	1.60	17.75
	Sugarcane plumegrass	*Saccharum giganteum*	0.09	1.35	0.63	8.50
	Southern cutgrass	*Leersia hexandra*	0.08	2.80	0.02	0.81
	Flatsedge	*Cyperus retrorsus*	0.07	1.50	0.13	2.55
	Flatsedge	*Cyperus haspan*	0.07	1.34	0.09	1.00
	Cogongrass	*Imperata cylindrica*	0.07	1.50	—	—
	Maidencane	*Panicum hemitomon*	0.06	1.34	0.24	3.25
	Rush	*Juncus megacephalus*	0.06	2.00	0.24	4.56
	Coastal foxtail	*Setaria corrugata*	0.06	1.25	—	—
	West indian dropseed	*Sporobolus indicus*	0.06	0.57	—	—
	Blue-joint panic grass	*Panicum tenerum*	0.05	1.25	0.67	14.75
	Arrowfeather	*Aristida purpurascens*	0.05	0.57	0.07	2.00

APPENDIX 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Graminoid	Erect-leaf witchgrass	*Dichanthelium erectifolium*	0.05	1.55	0.06	1.50
	Low nutrush	*Scleria verticillata*	0.05	1.32	0.04	1.25
	Sand cordgrass	*Spartina bakeri*	0.04	0.38	1.54	3.25
	Georgia nutrush	*Scleria georgiana*	0.04	0.82	0.01	0.13
	Panic grass	*Dichanthelium acuminatum*	0.04	0.25	—	—
	Flatsedge	*Cyperus polystachyos*	0.03	1.05	0.01	0.31
	Black sedge	*Schoenus nigricans*	0.03	0.07	—	—
	Rush fuirena	*Fuirena scirpoidea*	0.01	0.11	0.70	9.85
	Spike-rush	*Eleocharis geniculata*	0.01	0.25	0.33	4.60
	Wrinkled jointtailgrass	*Coelorachis rugosa*	0.01	0.13	0.18	3.50
	Big carpet grass	*Axonopus furcatus*	0.01	0.11	0.12	2.25
	Chaulky bushy bluestem	*Andropogon glomeratus*	0.01	0.18	0.09	1.50
	Chalky bluestem	*Andropogon virginicus*	0.01	0.16	0.04	0.31
	American cupscale	*Sacciolepis striata*	0.01	0.50	0.03	0.50
	Fall panic grass	*Panicum dichotomiflorum*	0.01	0.11	0.03	0.80
	Bottlebrush threeawn	*Aristida spiciformis*	0.01	0.25	—	—
	Few-flower nutrush	*Scleria pauciflora*	0.01	0.16	—	—
	Fringed nutrush	*Scleria ciliata*	0.01	0.07	—	—
	Many-head rush	*Juncus polycephalos*	0.01	0.05	—	—
	Sour paspalum	*Paspalum conjugatum*	0.01	0.25	—	—
	Torpedo grass	*Panicum repens*	0.01	0.32	—	—
	Spike-rush	*Eleocharis cellulosa*	0.00	0.07	0.02	0.50
	Slender fimbry	*Fimbristylis autumnalis*	0.00	0.07	0.00	0.03
	Awned hemicarpha	*Lipocarpha aristulata*	0.00	0.07	0.00	0.06
	Long-leaf cupgrass	*Eriochloa michauxii*	*0.00*	*0.07*	—	—
	Southern carpet grass	*Axonopus fissifolius*	*0.00*	*0.03*	—	—
	Tracy's beaksedge	*Rhynchospora tracyi*	—	—	*0.23*	*3.50*
	Inundated beaksedge	*Rhynchospora inundata*	—	—	*0.03*	*0.06*

APPENDIX 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
Graminoid	Baldwin's nutrush	Scleria baldwinii	—	—	0.02	0.75
	Bahiagrass	*Paspalum notatum*	—	—	0.01	0.03
	Florida paspalum	*Paspalum floridanum*	—	—	0.01	0.13
	Horned beaksedge	*Rhynchospora corniculata*	—	—	0.01	0.06
	Rush	*Juncus marginatus*	—	—	0.01	0.35
	Thalia lovegrass	*Eragrostis atrovirens*	—	—	0.01	0.31
	Piedmont beaksedge	*Rhynchospora breviseta*	—	—	0.00	0.05
Shrubs	Cabbage palm	*Sabal palmetto*	27.04	60.50	2.59	16.00
	Saw palmetto	*Serenoa repens*	21.61	28.25	0.22	0.72
	Wax-myrtle	*Myrica cerifera*	4.51	23.50	3.94	13.75
	Staggerbush	*Lyonia fruticosa*	2.35	15.75	—	—
	Saltbush	*Baccharis glomeruliflora*	1.88	15.50	0.63	5.25
	Gallberry	*Ilex glabra*	1.84	8.00	—	—
	Live oak	*Quercus virginiana*	1.39	17.75	0.08	0.25
	Winged sumac	*Rhus copallinum*	1.29	19.75	—	—
	Persimmon	*Diospyros virginiana*	1.20	11.00	0.14	1.43
	Myrsine	*Rapanea punctata*	0.76	8.00	0.14	0.50
	Slash pine	*Pinus elliottii*	0.54	17.50	0.02	0.55
	Brazilian pepper	*Schinus terebinthifolius*	0.38	3.00	0.06	0.31
	Shiny blueberry	*Vaccinium myrsinites*	0.38	7.50	—	—
	Swamp laurel oak	*Quercus laurifolia*	0.31	3.25	—	—
	Pond cypress	*Taxodium ascendens*	0.29	0.68	0.45	2.16
	Pineland shrubverbena	*Lantana depressa*	0.24	2.25	—	—
	Running oak	*Quercus pumila*	0.16	2.00	—	—
	Red maple	*Acer rubrum*	0.13	4.25	0.23	7.75
	Wild coffee	*Psychotria nervosa*	0.13	0.43	—	—
	Buckthorn	*Sideroxylon reclinatum*	0.09	1.75	0.27	1.75
	Saltbush	*Baccharis halimifolia*	0.05	0.50	0.01	0.06

Appendix 1. Continued.

Growth form	Common name	Scientific name	Pine habitat		Wet prairie habitat	
			Cover mean (%)	Frequency mean (%)	Cover mean (%)	Frequency mean (%)
	Swamp bay	*Persea palustris*	0.05	1.75	0.00	0.07
	Primrose willow	*Ludwigia octovalvis*	0.03	0.75	0.17	4.50
	Dahoon holly	*Ilex cassine*	0.03	0.75	0.01	0.25
	Pineland acacia	*Acacia pinetorum*	0.03	0.55	0.01	0.11
	Gopher apple	*Licania michauxii*	0.03	0.80	—	—
	Pond-apple	*Annona glabra*	0.03	0.11	—	—
	Shrub verbena	*Lantana camara*	0.03	0.34	—	—
	Pawpaw	*Asimina reticulata*	0.03	1.25	—	—
	Swamp dogwood	*Cornus foemina*	0.02	0.05	0.02	0.11
	Pop ash	*Fraxinus caroliniana*	0.01	0.38	—	—
	Blueberry	*Vaccinium darrowii*	0.00	0.07	—	—
	Florida strangler fig	*Ficus aurea*	0.00	0.07	—	—
	Sweet bay	*Magnolia virginiana*	0.00	0.09	—	—

A CHECKLIST OF NON-NATIVE VASCULAR PLANTS OBSERVED ON FLORIDA PANTHER NATIONAL WILDLIFE REFUGE

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Abstract: *Control of invasive, non-native plants requires constant vigilance and reporting on the occurrence of non-native plants in natural areas. We report the documentation of 122 species of non-native vascular plants from 49 families on the Florida Panther National Wildlife Refuge. Non-native species were predominantly represented by the Poaceae (21%) and the Fabaceae (12%). Of the 122 species observed, 22 (18 %) were categorized as category I invasive plants by the Florida Exotic Pest Plant Council. Most species (69%) were reported in areas associated with previous or current human activity, such as roads, canals, spoil areas, and areas previously inhabited by humans.*

The occurrence and spread of non-native plants in south Florida is a serious concern to land managers due to the potential for these species to become invasive, displace native plants, and adversely affect wildlife that depend upon native plant communities. Under worst case scenarios, invasive non-native plants may dominate native habitats to the point where ecological function is grossly altered (Austin, 1998; Meffe and Carroll, 1994; Westbrooks 1998). For example, Melaleuca (*Melaleuca quinquenervia*) and Brazilian pepper (*Schinus terebinthifolius*) are two invasive non-native species that dominate many natural areas in south Florida and have been the target of extensive control programs by local, state, and federal organizations (Brown and Brown, 1998; Clark, 1998; Clark et al. 1997).

Unfortunately, the spread of many additional invasive species, such as cogon grass (*Imperata cylindrica*) pose serious threats to native plant and animal communities in south Florida. In addition to negative impacts on native habitats, non-native plants such as tropical soda apple (*Solanum khasianum*) can negatively affect agricultural operations (Mullahey et al., 1996) and aquatic species such as hydrilla (*Hydrilla verticillata*) pose problems for water management (Langeland and Burks, 1998). Consequently, it is important to be vigilant in our efforts to track and to control invasive and potentially invasive non-native species to the greatest extent possible (Bradley and Gann, 1998; Brown and Brown, 1998). With regional efforts at reporting the occurrence of non-native plants and coordinated attempts to control invasive exotics, the effectiveness of control efforts may be maximized (Stocker, 1998). We report a list of non-native plants observed on the

Florida Panther National Wildlife Refuge (FPNWR), provide invasive ranking for each species as categorized by the Florida Exotic Pest Plant Council (FLEPPC), and provide comments regarding distribution and spread of each species on the refuge.

METHODS—The FPNWR was established during 1989 and encompasses 10,636 ha in Collier County in southwest Florida. The FPNWR supports a mosaic of habitats typical of the Big Cypress Basin watershed, including slash pine (*Pinus elliottii* var. *densa*) flatwoods, cypress (*Taxodium ascendens, T. distichum*) and mixed swamps, marshes, wet prairies, and hardwood hammocks (Duever et al., 1986). Resource extraction by humans that historically occurred on the FPNWR included extensive clear cutting of slash pine and cypress during the early 1900's, cattle grazing, hunting, and minor amounts of crop production and oil extraction (Richardson, 1999). Other evidence of human activity exists at old homesteads and a former hunting camp, and as a network of trails, roads, fire lanes, and even the remnants of old railway trams used to haul timber. Highways, canals, and man-made ponds exist near the eastern and southern borders of the refuge.

During 1996–1998 we documented observations of non-native plants on the FPNWR during qualitative surveys of hammocks, wet prairies, slash pine flatwoods, canals and other habitats. We also reviewed lists of observations of non-native plants by other persons, primarily Dr. Robert Read (Smithsonian Institution, retired), other researchers, and employees of the FPNWR (FPNWR unpublished information). We indicate which species we have confirmed to exist on the refuge and those that have only been reported by other persons. We also provide FLEPPC invasive category ranking and brief comments on habitats where non-native species were observed and whether human activity could be directly linked with establishment or spread of these plants. Species listed in this report follow the nomenclature of Wunderlin (1998).

RESULTS—A total of 122 species of non-native vascular plants representing 49 families have been reported to occur on FPNWR (Appendix 1). We confirmed the presence of the majority (72%) of these species and documentation of the remaining species came from reliable sources. Dominant taxa representing the non-native vascular plants on FPNWR were the Poaceae (26 species, 21% of total) and the Fabaceae (15 species, 12% of total). Of the 122 species observed, 22 (18%) were categorized as category I invasive plants by the FLEPPC (Appendix 1).

Pine, wet prairie, and tropical hammocks were habitats best represented by this species list. The majority (69%) of non-native species were observed in areas that were associated with previous or current human activity. Examples included roads, canals, spoil areas, and areas of human habitation, all of which represent either sources of initial establishment as the result of intentional plantings or potential conduits for dispersal of non-native plants on vehicles, via waterways, and in response to soil disturbance. We documented 18 species (15%) associated with roads, trails and spoil areas, 5 species (4%) associated with canals and created ponds, and 61 species (50%) associated with areas of previous human habitation (Table 1). Some non-native species were observed only around areas of previous human habitation and exhibited no signs of spreading (Table 1). Many planted species, however, clearly are spreading and some, such as Mexican flame vine (*Pseu-*

dogynoxys chenopodioides) and cogon grass were abundant or dominant in areas where planted.

Discussion—Invasive non-native plants are altering the ecology of natural areas and causing concern among resource managers and agricultural enterprises throughout the United States (Westbrooks, 1998). The establishment of non-native biota has been identified along with contamination and habitat destruction as one of the three major forms of environmental pollution, and the only form of environmental pollution that likely can never be reversed (Coblentz, 1990). Florida, and particularly south Florida, has been particularly vulnerable to invasion by non-native species (Simberloff, 1994; Simberloff et al., 1997). It is estimated that 29% of all species growing independently in natural areas in Florida are non-native plants (Langeland and Stocker, 1997; Wunderlin et al., 1996). In Florida and elsewhere, human activity, both intentional and unintentional, is largely responsible for the introduction and distribution of non-native plants throughout natural areas and agricultural landscapes.

The establishment of the majority of non-native vascular plants documented on FPNWR can be linked directly to disturbance of native communities by previous human activities on the refuge, such as homesteading, road and canal construction, and resource extraction of fill dirt or oil. Several non-native species observed on FPNWR are recognized as highly invasive (Appendix 1). As expected, the occurrence of the highly invasive Brazilian pepper, melaleuca, and Australian pine (*Casuarina equisetifolia*) were documented on the refuge. These three species are well-established throughout natural areas in south Florida and have been the focus of aggressive control efforts (Clark et al., 1997; Langeland and Burks, 1998; Langeland and Stocker, 1997). For example, as of 1998 the Everglades National Park alone had expended 14,000 labor hours and $546,000 in herbicide and helicopter costs to control melaleuca and Australian pine, and Brazilian pepper is estimated to infest over 400,000 ha in the state (Langeland and Burks, 1998).

In addition to the anticipated problem plants that are established throughout south Florida, several additional species were documented that are capable of dominating plant communities. Cogon grass, which is rated as one of 10 worst weeds in the world (Holm et al., 1977), occurred sporadically on the refuge and has been the target of an aggressive control campaign. Cogon grass was intentionally planted by contractors to "restore" areas used as platforms for oil extraction prior to establishment of the FPNWR (Richardson, 1999). There were many other species documented on the refuge that are highly invasive (Table 1), but a detailed discussion of each of these is beyond the scope of this paper. Of particular note, however, was the documentation of the old world climbing fern (*Lygodium microphyllum*), which has been spreading in south Florida and is a subject of considerable concern among resource managers (Langeland and Burks 1998). We did not confirm the occurrence of the old world climbing fern during our surveys, but vigilance and immediate control efforts for this species throughout south Florida is warranted. Assistance in the identification, reporting, and control of old world climbing fern and other invasive, non-native plant species is available on the FLEPPC website (FLEPPC ONLINE:2000).

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APPENDIX 1. List of non-native vascular plants observed on the Florida Panther National Wildlife Refuge with invasiveness rankings by the Florida Exotic Pest Plant Council (FLEPPC), whether we confirmed the occurrence of a species reported by other investigators, and observations and comments on locations and whether spreading was evident.

Common name	Family	Genus species	Fleppc rank	Confirmed	Observations & comments
Yerba	Acanthaceae	*Blechum pyramidatum*	—	Y	Hammocks at old homesteads and hunting camp
Ti plant	Agavaceae	*Cordyline terminalis*	—	Y	Hammock at old homestead
African bowstring hemp	Agavaceae	*Sanseviera hyacinthoides*	II	Y	Hammocks at old homesteads and hunting camp
Globe amaranth	Amaranthaceae	*Gomphrena serrata*	—	N	FPNWR unpublished information
Brazilian pepper	Anacardiaceae	*Schinus terebinthifolius*	I	Y	Dominates disturbed areas, especially transitional areas between wetlands/uplands
Mango	Anacardiaceae	*Mangifera indica*	—	N	Hammock (FPNWR unpublished information)
Madagascar periwinkle	Apocynaceae	*Catharanthus roseus*	—	Y	Hammocks at old homesteads and hunting camp
Golden trumpet allamanda	Apocynaceae	*Allamanda cathartica*	—	Y	Hammocks at old homesteads
Wild taro	Araceae	*Colocasia esculenta*	I	Y	FPNWR unpublished information
Water lettuce	Araceae	*Pistia stratiotes*	I	Y	Canals, lake, open ponds in cypress swamp
Arrow-head vine	Araceae	*Syngonium podophyllum*	II	Y	Hammocks at old homesteads, localized spreading
Golden pothos	Araceae	*Epipremnum pinnatum*	II	Y	Hammocks at old homesteads, localized spreading
Malanga	Araceae	*Alocasia macrorrhizos*	—	Y	Hammocks at old homesteads
Norfolk Island pine	Araucariaceae	*Araucaria heterophylla*	—	N	Hammocks at old homesteads
Queen palm	Arecaceae	*Syagrus romanzoffianum*	—	Y	Hammocks at old homesteads
Washington palm	Arecaceae	*Washingtonia robusta*	—	Y	Hammocks at old homesteads
Pygmy date palm	Arecaceae	*Phoenix roebelenii*	—	Y	Hammocks at old homesteads
Common sowthistle	Asteraceae	*Sonchus oleraceus*	—	Y	Scattered in pinelands
Tridax	Asteraceae	*Tridax procumbens*	—	N	FPNWR unpublished information
Oriental hawksbeard	Asteraceae	*Youngia japonica*	—	Y	Hammocks at old homesteads and hunting camp

APPENDIX 1. Continued.

Common name	Family	Genus species	Fleppc rank	Confirmed	Observations & comments
Mexican flame vine	Asteraceae	*Pseudogynoxys chenopodioides*	—	Y	Dominates in cleared area around old homestead
Bay Biscayne wedelia	Asteraceae	*Wedelia trilobata*	II	N	FPNWR unpublished information
Erucastrum	Brassicaceae	*Erucastrum gallicum*	—	N	FPNWR unpublished information
Pineapple	Bromeliaceae	*Annas comosus*	—	Y	Spreading into hammocks around old homesteads
Night blooming cactus	Cactaceae	*Hylocereus undatus*	—	Y	Hammock at old homestead, persistent epiphyte
Papaya	Caricaceae	*Carica papaya*	—	Y	Hammocks at old homesteads
Australian pine, horse-tail casuarina	Casuarinaceae	*Casuarina equisetifolia*	I	Y	Hammocks at old homesteads, disturbed areas, pine flatwoods
Oyster-plant	Commelinaceae	*Tradescantia spathacea*	—	Y	Hammocks at old homesteads
Wandering jew	Commelinaceae	*Tradescantia zebrina*	—	Y	Hammocks at old homesteads, evidence of spreading
Sweet potato	Convolvulaceae	*Ipomoea batatas*	—	N	FPNWR unpublished information
Life-plant	Crassulaceae	*Kalanchoe pinnata*	—	Y	Hammocks at old homesteads
Sago palm	Cycadaceae	*Cycas revoluta*	—	Y	Hammocks at old homesteads
Awned hemicarpha	Cyperaceae	*Lipocarpha aristulata*	—	Y	Along trail in pinelands
Air potato	Dioscoreaceae	*Dioscorea bulbifera*	I	Y	Hammocks at old homesteads
Marsh caperonia	Euphorbiaceae	*Caperonia palustris*	—	Y	Common in disturbed, moist open areas, especially power easements along highway, transitional areas, and wet prairies
Croton	Euphorbiaceae	*Codianum variegatum*	—	Y	Hammocks at old homesteads
Castor-bean	Euphorbiaceae	*Ricinus communis*	II	Y	Hammocks at old homesteads
Rosary pea	Fabaceae	*Abrus precatorius*	I	Y	Hammocks at old homesteads
Woman's-tongue	Fabaceae	*Albizia lebbeck*	I	N	FPNWR unpublished information
Alysicarpus	Fabaceae	*Alysicarpus vaginalis*	—	N	FPNWR unpublished information
Rattle-box	Fabaceae	*Crotalaria lanceolata*	—	N	FPNWR unpublished information

APPENDIX 1. Continued.

Common name	Family	Genus species	Fleppc rank	Con-firmed	Observations & comments
Rattlesnake weed	Fabaceae	*Crotalaria spectabilis*	—	Y	Hammocks at old homesteads, pinelands along road, along power easement
Indian rosewood	Fabaceae	*Dalbergia sissoo*	II	N	FPNWR unpublished information
Indigo	Fabaceae	*Indigofera spicata*	—	N	FPNWR unpublished information
Lead tree	Fabaceae	*Leucaena leucocephala*	II	Y	FPNWR unpublished information
Wild bush bean	Fabaceae	*Macroptilium lathyroides*	—	Y	Hammocks at old homesteads and in disturbed, open, wet areas
Cassia	Fabaceae	*Senna pendula*	I	N	FPNWR unpublished information
Rattlebox	Fabaceae	*Crotalaria pallida*	—	Y	Hammocks at old homesteads and in disturbed, open, wet areas
Orchid tree	Fabaceae	*Bauhinia purpurea*	—	Y	Hammocks at old homesteads
Golden shower	Fabaceae	*Cassia fistula*	—	Y	Hammocks at old homesteads
Wondering cowpea	Fabaceae	*Vigna speciosa*	—	Y	Hammocks at old homesteads
Golden rain tree	Fabaceae	*Koelreuteria formosana*	—	Y	Hammocks at old homesteads
Parrot-feather	Haloragaceae	*Myriophyllum aquaticum*	—	N	FPNWR unpublished information
Lobster-claw	Heliconiaceae	*Heliconia lataspathia*	—	Y	Hammocks at old homesteads, localized spreading
Hydrilla	Hydrocharitaceae	*Hydrilla verticillata*	I	Y	Abundant to dominant in canals along highways
Pale yellow iris	Iridaceae	*Iris pseudacorus*	—	Y	Hammocks at old homesteads, localized spreading
Tropical bushmint	Lamiaceae	*Hyptis mutabilis*	—	Y	Hammocks at old homesteads and along roads
Comb bushmint	Lamiaceae	*Hyptis pectinata*	—	N	FPNWR unpublished information
John Charles	Lamiaceae	*Hyptis verticillata*	—	Y	Hammocks at old homesteads and in disturbed areas
Waxweed	Lythraceae	*Cuphea carthagenensis*	—	Y	Scattered throughout in wet prairies
Caesar-weed	Malvaceae	*Urena lobata*	II	Y	Scattered throughout pinelands and disturbed upland areas

Appendix 1. Continued.

Common name	Family	Genus species	Fleppc rank	Confirmed	Observations & comments
Turk's-cap mallow	Malvaceae	*Malaviscus penduliflorus*	—	Y	Hammocks at old homesteads
Garden rose mallow	Malvaceae	*Hibiscus rosa-sinensis*	—	Y	Hammocks at old homesteads, no evidence of spreading
Hairy water fern	Marsileaceae	*Marsilea vestita*	—	N	FPNWR unpublished information
Chinaberry	Meliaceae	*Melia azedarach*	I	Y	Hammocks at old homesteads
Surinam cherry	Myrtaceae	*Eugenia uniflora*	I	Y	Hammocks at old hunting club
Melaleuca	Myrtaceae	*Melaleuca quinquenervia*	I	Y	Scattered in pinelands and wet prairies
Guava	Myrtaceae	*Psidium guajava*	I	Y	Hammocks at old homesteads and hunting club and other hammocks, along former railroad trams in cypress swamp
Jambolan plum	Myrtaceae	*Syzygium cumini*	I	Y	Hammocks at old hunting club; ID uncertain (*S. jambos*?)
Rose apple	Myrtaceae	*Syzygium jambos*	II	Y	Hammocks at old hunting club, ID uncertain (*S. cumini*?)
Naiad	Najadaceae	*Najas wrightiana*	—	N	FPNWR unpublished information
Primrose willow	Onagraceae	*Ludwigia peruviana*	—	Y	Disturbed marsh areas
Monk orchid	Orchidaceae	*Oeceoclades maculatus*	II	Y	Hammocks at old homesteads and elsewhere
Lawn orchid	Orchidaceae	*Zeuxin strateumatica*	—	Y	Hammocks at old homesteads and hunting club
Cypress peperomia	Piperaceae	*Peperomia glabella*	—	N	FPNWR unpublished information
Common plantain	Plantaginaceae	*Plantago major*	—	N	FPNWR unpublished information
Pitted bluestem	Poaceae	*Bothriochloa pertusa*	—	N	FPNWR unpublished information
Bermudagrass	Poaceae	*Cynodon dactylon*	—	Y	Hammocks at old homesteads and hunting club
Crowfootgrass	Poaceae	*Dactyloctenium aegyptium*	—	Y	Along roads, disturbed areas
Jungle rice	Poaceae	*Echinochloa colona*	—	N	FPNWR unpublished information
Barnyardgrass	Poaceae	*Echinochloa crusgalli*	—	N	FPNWR unpublished information
Goosegrass	Poaceae	*Eleusine indica*	—	Y	Hammocks at old homesteads

Appendix 1. Continued.

Common name	Family	Genus species	Fleppc rank	Con-firmed	Observations & comments
Thalia lovegrass	Poaceae	*Eragrostis atrovirens*	—	Y	Fire lanes and disturbed areas, wet prairies; ID uncertain (*E. bahiensis*?)
Bahia lovegrass	Poaceae	*Eragrostis bahiensis*	—	Y	Disturbed areas (e.g., fire lanes) and wet prairies; ID uncertain (*E. atrovirens*?)
Gophertail lovegrass	Poaceae	*Eragrostis ciliaris*	—	Y	Disturbed areas
Jaragua	Poaceae	*Hyparrhenia rufa*	—	Y	Disturbed areas (e.g., former oil drilling pad)
Cogongrass	Poaceae	*Imperata cylindrica*	I	Y	Formerly dominant at oil pads, significantly reduced by herbicide treatments, also present at other disturbed sites (e.g., fire lanes), evidence of spreading into pine habitat
Silk reed	Poaceae	*Neyraudia reynaudiana*	I	N	FPNWR unpublished information – herbarium specimen – ID uncertain (*E. atrovirens*?; looks like *Phragmites australis*)
Torpedo grass	Poaceae	*Panicum repens*	I	Y	Dominant in most wet, open fire lanes, dominate in abandoned agricultural areas, scattered throughout in wet, open areas
Panama paspalum	Poaceae	*Paspalum fimbriatum*	—	N	FPNWR unpublished information
Bahiagrass	Poaceae	*Paspalum notatum*	—	Y	Hammocks at old homesteads and hunting club, and dry disturbed sites (e.g., dry fire lanes)
Vasey grass	Poaceae	*Paspalum urvillei*	—	Y	Disturbed sites (e.g., fire lanes)
Elephantgrass	Poaceae	*Pennisetum purpureum*	I	N	FPNWR unpublished information
Natalgrass	Poaceae	*Rhynchelytrum repens*	II	Y	Dry disturbed areas (e.g., spoil deposits) and disturbed areas in pinelands
Sugar-cane	Poaceae	*Saccharum officinarum*	—	Y	Disturbed areas along highway
Smutgrass	Poaceae	*Sporobolus indicus*	—	Y	Hammocks at old homesteads and hunting camp, dominant in some disturbed areas (e.g., fire lanes)

Appendix 1. Continued.

Common name	Family	Genus species	Fleppc rank	Con-firmed	Observations & comments
St. Augustine grass	Poaceae	*Stenotaphrum secundatum*	—	Y	Hammocks at old homesteads and hunting camp
Maize	Poaceae	*Zea mays*	—	N	FPNWR unpublished information
Browntop millet	Poaceae	*Urochloa ramosa*	—	N	FPNWR unpublished information
Itchgrass	Poaceae	*Rottboellia cochinchinensis*	—	N	FPNWR unpublished information
Paragrass	Poaceae	*Urochloa mutica*	I	Y	Dominant in some marsh areas along highway, common in canals
Trompetilla	Poaceae	*Hymenachne amplexicaulis*	I	Y	Shaded wetland behind old homestead
Water-hyacinth	Pontederiaceae	*Eichhornia crassipes*	—	Y	Marsh along highway and in canals
Ladder brake	Pteridaceae	*Pteris vittata*	II	Y	Disturbed, dry, shaded areas, present in pinelands
Spermacoce	Rubiaceae	*Spermacoce verticillata*	—	Y	Disturbed fill areas
Red ixora	Rubiaceae	*Ixora coccinea*	—	Y	Hammocks at old homesteads and hunting camp
Sour orange	Rutaceae	*Citrus aurantium*	—	Y	Hammocks at old homesteads and hunting camp, scattered throughout hammocks
Lemon	Rutaceae	*Citrus limon*	—	Y	Hammocks at old homesteads and hunting camp
Grapefruit	Rutaceae	*Citrus* × *paradisi*	—	Y	Hammocks at old homesteads and hunting camp
Key lime	Rutaceae	*Citrus aurantifolia*	—	Y	Hammocks at old homesteads and hunting camp
Sweet orange	Rutaceae	*Citrus sinensis*	—	Y	Hammocks at old homesteads and hunting camp
Old World climbing fern	Schizaeaceae	*Lygodium microphyllum*	I	N	FPNWR unpublished information
Malayan false-pimpernel	Scrophulariaceae	*Lindernia crustacea*	—	Y	Moist shaded fire lanes
Tobacco	Solanaceae	*Nicotiana tabacum*	—	N	FPNWR unpublished information
Traveler's palm	Strelitziaceae	*Ravenala madagascariensis*	—	Y	Hammock at old homestead
Downy maiden fern	Thelypteridaceae	*Thelypteris dentata*	—	N	FPNWR unpublished information

APPENDIX 1. Continued.

Common name	Family	Genus species	Fleppc rank	Con-firmed	Observations & comments
Shrub verbena	Verbenaceae	*Lantana camara*	I	Y	Common in disturbed fill areas, fire lanes, scattered in pinelands, (may hybridize with *L. depressa* var. *sanibelensis*)
South american vervain	Verbenaceae	*Verbena bonariensis*	—	N	FPNWR unpublished information
Javanese glorybower	Verbenaceae	*Clerodendron speciosissimum*	—	Y	Hammocks at old homesteads and hunting camp
Yellow-eyed grass	Xyridaceae	*Xyris jupicai*	—	N	FPNWR unpublished information
Shell ginger	Zingiberaceae	*Alpinia zerumbet*	—	Y	Hammocks at old homesteads
Ginger	Zingiberaceae	*Alpinia purpurata*	—	N	Hammocks at old homesteads, species ID uncertain

POLLINATOR VISITATION TO *HYPERICUM CUMULICOLA* (HYPERICACEAE), A RARE FLORIDA SCRUB ENDEMIC

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ABSTRACT: *Pollinator visitation may affect fecundity and gene flow, and itself is affected by myriad habitat features. We examined the relative effects of flower density, fruiting plant density, and fire history on pollinator visitation rate to patches of* Hypericum cumulicola, *a rare, self-compatible Florida scrub endemic. We also measured seed set across a range of pollinator visitation rates. Small native solitary bees of the genus* Dialictus *(Hymenoptera: Halictidae) made 99% (348/ 350) of all observed visits. Visiting* Dialictus *were supported atop the anthers by stiff filaments as they harvested the abundant pollen, but were too small to make frequent contact with the stigmas during foraging.* Dialictus *bees were observed contacting stigmas most often when first arriving at flowers, likely increasing the chances of outcrossing. While short visits (< 10 s) occurred all morning, duration of the longest visits decreased as the morning progressed, probably reflecting depleted pollen supplies. Visitation rate (visits per plant per minute) increased with flower density (ln flowers per m^2) indicating that visitation rate to* H. cumulicola *is positively density-dependent. Fire history, fruiting plant density, and flower height did not directly affect visitation rate. Populations that had higher visitation rates had higher average seed set. Since flowering density decreases with time since last fire, long unburned patches of* H. cumulicola *suffer lower fecundity, and are likely more susceptible to inbreeding depression due to the compound effects of few potential mates and low pollinator visitation rates.*

HIGHLANDS scrub Hypericum (*Hypericum cumulicola*) is a federally endangered perennial herb, endemic to the Lake Wales Ridge of central Florida (Harper, 1948; Christman and Judd, 1990). It occurs primarily in the rosemary phase of Florida scrub vegetation, a naturally fragmented community dominated by Florida rosemary (*Ceratiola ericoides*) and scrub oaks (*Quercus spp.*) that is disturbed by fire every 20–80 years (Menges and Hawkes, 1998). Within rosemary scrub, *H. cumulicola* is restricted to open areas of xeric white sand (Archbold, St. Lucie) between patches of rosemary and oaks (Quintana-Ascencio and Morales-Hernandez, 1998). This patchy habitat and distribution make *H. cumulicola* a likely candidate to exhibit metapopulation dynamics (Quintana-Ascencio and Menges, 1996). The genetic structure of patches also supports the possibility that *H. cumulicola* exists in metapopulations. Dolan and co-workers (1999) found a high degree of differentiation and restricted gene flow among patches of *H. cumulicola* ($F_{ST} = 0.73$, $N_m = 0.09$).

Rates of pollinator visitation to flowering plants are often positively density-dependent, meaning that the rate at which pollinators visit flowers usually increases as density of flowering plants increases (Silander, 1978; Thomson, 1981, 1988; Kunin, 1992, 1993; Andersson, 1996; but for exceptions see Schmitt, 1983; Kilnkhamer and de Jong, 1990; Walters and Stiles, 1996). For example, Kunin (1993) found that quantity (visitation rate) and quality (pollinator efficiency) of pollinator service decreased significantly with decreasing density of flowering *Brassica kaber* (Brassicaceae) plants. Whether pollinator visitation rate to *H. cumulicola* is density-dependent or independent has important implications for gene flow and, hence, maintaining genetic diversity in this rare species.

In *H. cumulicola* patches, the density of fruiting plants is a good predictor of flower density ($n = 15$; $r = 0.64$; $P = 0.01$). Fruiting plant density can then be measured as an index of a population's flower density over the course of one season. If pollinators visit *H. cumulicola* by trapline foraging, returning to patches that proved rewarding in the past (Thomson, 1982), then patches with a history of high flower density, as indicated by high fruiting plant density, may receive disproportionately high rates of visitation.

The fire history of a site may directly affect pollinator visitation rate by changing the structural composition of a rosemary bald. As time since last fire increases, growth of rosemary, oaks, and ground lichens fill in patches of open sand. Sporadic fire maintains the open sand habitat favorable for the maintenance of *H. cumulicola* patches by reducing competition from shrubs and lichens, and greatly increases the density of flowering *H. cumulicola* plants (Quintana-Ascencio and Morales-Hernandez, 1998).

H. cumulicola is self-compatible, but cross-pollination by insect visitors significantly increases the proportion of viable seed produced (Evans and Menges, 1998). Factors that cause decreased pollinator visitation should lead to decreased fecundity, potentially affecting the ability of *H. cumulicola* to persist locally, and could also decrease gene flow. In this study, we document the pollination ecology of *H. cumulicola,* examine the relative effects of flower density, fruiting plant density, and fire history on pollinator visitation rates, and determine the effect of visitation rate on seed set in *H. cumulicola* populations.

MATERIALS AND METHODS—*Study sites*—We examined the pollination ecology of *Hypericum cumulicola* (Small) P. Adams at Archbold Biological Station (ABS), a 1,968 hectare preserve located at the southern end of Florida's Lake Wales Ridge (Highlands County, latitude W81 21′, longitude N27 10′, Sections 6, 7, 18, 19, 30,31 of T38S R30E). A detailed description of the vegetation, soils, and climate of ABS is given by Abrahamson and co-workers (1984). ABS encompasses a variety of scrub habitats including approximately 36 hectares of the rosemary phase of sand pine scrub (Abrahamson et al., 1984). We selected 15 spatially distinct (>30 meters) *H. cumulicola* patches (Fig. 1), including in our sample the entire range of *H. cumulicola* densities and fire history (time since last fire) found at ABS.

H. cumulicola *population structure*—We established the center-most flowering individual in each *H. cumulicola* patch as the target plant. The target plant served as the center of a

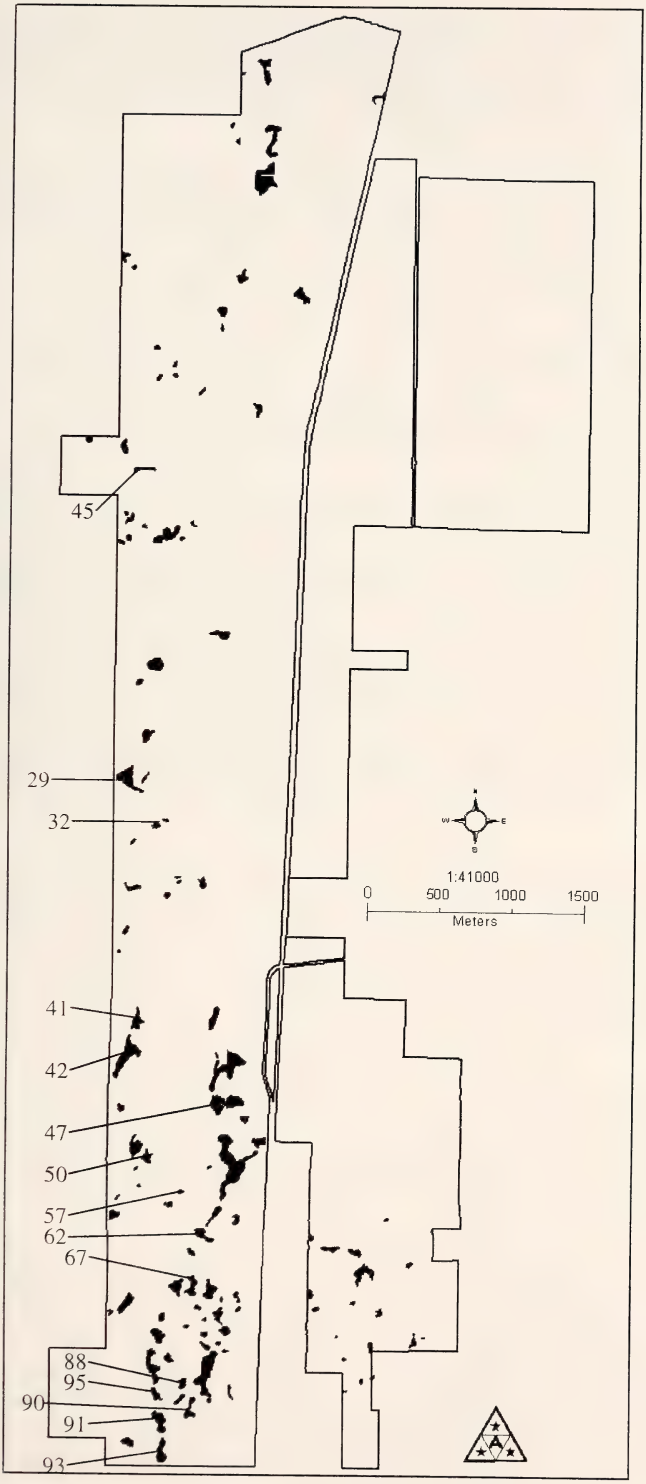

FIG. 1. Distribution of rosemary scrub patches at Archbold Biological Station, FL. The study populations are indicated by patch number.

circular plot (radius = 3 m) within which we counted all *H. cumulicola* flowers open on the morning of pollinator observations and all *H. cumulicola* individuals in fruit. We also included the flowering conspecific closest to the target plant (nearest neighbor) in our floral visitor observations. We measured distances between the target and nearest neighbor plants and height of each of their flowers from the ground.

Pollinator visitation rates—We observed insect visitation to *H. cumulicola* over a 15-day period in late September/ early October, near the end of the flowering season (April–October; Menges and Salzman, 1992). We sampled one population per day in random order and made a total of 32 hours of pollinator observations. In each population, we observed insect visitor behavior on all flowers of the target plant (1 to 5 flowers/ plant) and the nearest neighbor (1 to 5 flowers/ plant) for 2 to 3 hours on one morning between 0700 and 1200. Since the lifetime of individual *H. cumulicola* flowers is only a few hours in one morning (U.S. Fish and Wildlife Service, 1999), we ensured that observations were made during the peak visitation period. For each observed visit we recorded time of visit, genus of visitor, identity of flower visited, duration of visit, and identity of subsequent flower visited (target, nearest neighbor, or unknown). We defined a visit as an insect making contact with the anthers, either by landing directly on the anthers or by landing on a petal and climbing onto the anthers. Pollinator observations ceased 30 minutes after the onset of floral dehiscence and subsequent absence of pollinators.

Seed set—Following pollinator observations we marked each of the target and nearest neighbor flowers with uniquely colored threads. We collected mature, red fruit capsules 21 days after flowering. We recovered 39% (20/51) of the marked fruits. Our low rate of recovery was likely due to our method of marking. *H. cumulicola* has very flexible stems which sway a great deal, even in light wind. Presumably our marking thread became entangled in adjacent vegetation, removing the marked fruit. In addition to the marked fruits, we collected 15–20 fruits at random from each population to determine average seed set. We examined capsules under a dissecting microscope and tallied brown, filled, developed seeds and white, small, aborted seeds. Seed set was expressed as the proportion of total seeds that were developed.

Data analysis—We conducted path analyses to determine the relative importance of variables affecting pollinator visitation rate to *H. cumulicola.* Developed by Sewell Wright, path analysis is a general form of multiple regression that allows the quantification of the relative strengths of both direct and indirect effects of multiple predictor variables on a response variable (Mitchell, 1993). First, we constructed a path diagram, a priori, illustrating putative relationships between flower density (natural logarithm-transformed flowers per m^2), fruiting plant density (fruiting plants per m^2), fire history (years since last fire), and pollinator visitation rates (visits per plant per minute, Fig. 2). This model was the most biologically reasonable. Flower height (31.8 ± 1.2 cm; $n = 15$) was a poor predictor of visitation rate ($r = 0.26$; $P > 0.33$) and was not considered in the model. We then used path analysis to estimate the magnitude and direction of causal interactions, often the main emphases of path analysis (Sokal and Rohlf, 1981). Because we could only recover fruits from 12 of the 15 populations, we did not include seed set as a response variable in the path analysis, but determined how it was affected by visitation rate via linear regression analysis.

RESULTS—*Pollinator observation*—The pollinator visitation rate to *H. cumulicola* was 0.19 ± 0.02 visits per minute per plant (Table 1). Species of *Dialictus* (Hymenoptera: Halictidae), a genus of small solitary bees, were the most common visitors to *H. cumulicola,* making 99% of all observed visits (348/ 350). *Augochlorella sp.* (Hymenoptera: Halictidae) made the remaining two visits. *Dialictus* bees were present in *H. cumulicola* patches for an average of 63.9 ± 5.3 minutes each morning. The time span that bee

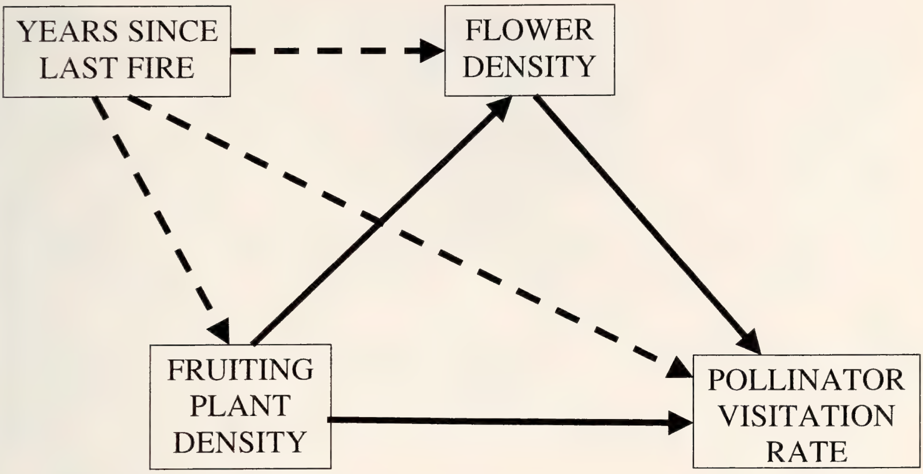

FIG. 2. A priori path diagram showing putative relationships between fire history (years since last fire), flower density, fruiting plant density, and pollinator visitation rate to *Hypericum cumulicola.* Solid lines indicate expected positive effects and dashed lines indicated expected negative effects. Flower height was not included since it was not related to any other variable.

pollinators were present in a population was not related to mean air temperature (75.2 ± 0.7 °F; n = 15; Spearman correlation coefficient $r_s = 0.16$; $P > 0.56$).

Visiting *Dialictus spp.* were supported atop the anthers by the stiff filaments. The bees harvested the abundant pollen and were too small to make

TABLE 1. Summary of flower density, fruiting plant density, and visitation rates for 15 study populations of varying times since fire (1996) at Archbold Biological Station.

Patch number	Time since fire (years)	Fruiting plant density (plants/m²)	Flower density (flowers/m²)	Visitation rate (visits/plant/min.)
41	3	1.60	2.10	0.29
50	3	1.10	0.78	0.27
95	10	1.10	0.74	0.27
67	10	0.39	0.11	0.26
62	32	1.20	0.18	0.25
32	11	0.88	1.30	0.23
93	24	2.80	0.36	0.23
88	10	0.71	0.78	0.19
29	11	0.64	0.42	0.19
57	3	1.40	0.60	0.18
42	3	9.30	2.20	0.18
91	10	3.40	2.40	0.17
45	12	1.10	0.32	0.15
47	20	0.53	0.18	0.12
90	10	0.42	0.21	0.09
Mean ± SE	11.5 ± 2.0	1.8 ± 0.6	0.8 ± 0.2	0.20 ± 0.02

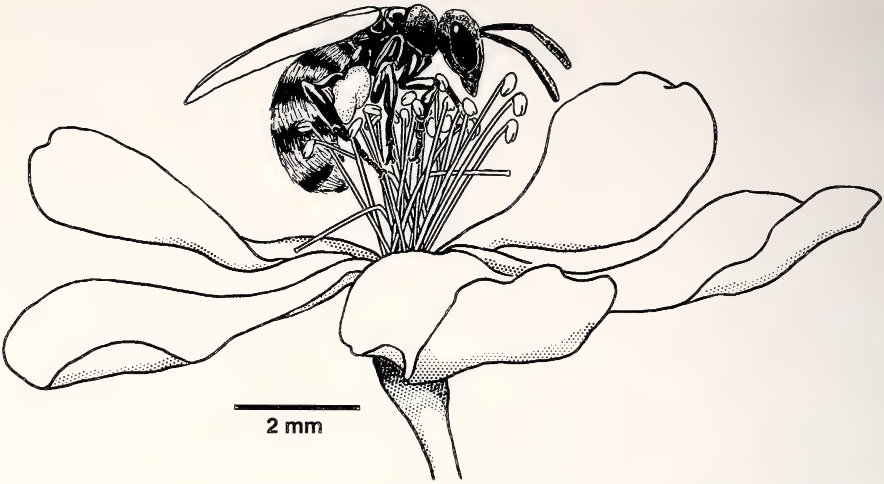

FIG. 3. Line drawing of a *Dialictus* bee visiting a flower of *Hypericum cumulicola*. *Dialictus spp.* made 99% of all observed visits (348/ 350).

frequent contact with the stigmas during foraging (Fig. 3). Bees were observed contacting stigmas most often when they first arrived at flowers. *Dialictus spp.* commonly approached a flower by landing on a flower petal, then climbing onto the column of anthers, and, in the process, contacting the stigmas. Though short visits (< 10 s) occurred throughout the morning, the duration of the longest visits (> 90 s) decreased as the morning progressed (Fig. 4).

Pollinator visitation rate and seed set—The model including time since fire, flowering history, and flower density explained 32% of variation in visitation rate. The natural log of flower density (mean ± SE = 0.8 ± 0.2 flowers per m^2; n = 15; Table 1) had the greatest direct effect on pollinator visitation rate (direct effect, $p_{DE} = 0.64$; Table 2, Fig. 5). The relationship was positive, indicating that *Dialictus spp.* visitation to *H. cumulicola* patches may be positively density-dependent. Fruiting plant density (1.8 ± 0.6 fruiting plants per m^2; n = 15; Table 1) and fire history had negative direct effects on visitation rate and explained less of the variation in visitation rate ($p_{DE} = -0.49$ and -0.02 respectively; Table 2, Fig. 5).

Since there were no indirect effects of flower density on pollinator visitation rate in our model, the total effect of flower density had a large positive effect on pollinator visitation rate, explaining 64% of the variation (Table 2). Counter to expectations, visitation rate decreased with fruiting plant density ($p_{TE} = -0.21$; Table 2). Recently burned sites had greater pollinator visitation rates, mainly as an indirect effect of higher flower densities in recently burned sites ($p_{TE} = -0.27$; Table 2). Average seed set ranged from 71% to 91% and increased significantly with pollinator visitation rate (n = 12; $r^2 = 0.40$; $P < 0.05$; Fig. 6).

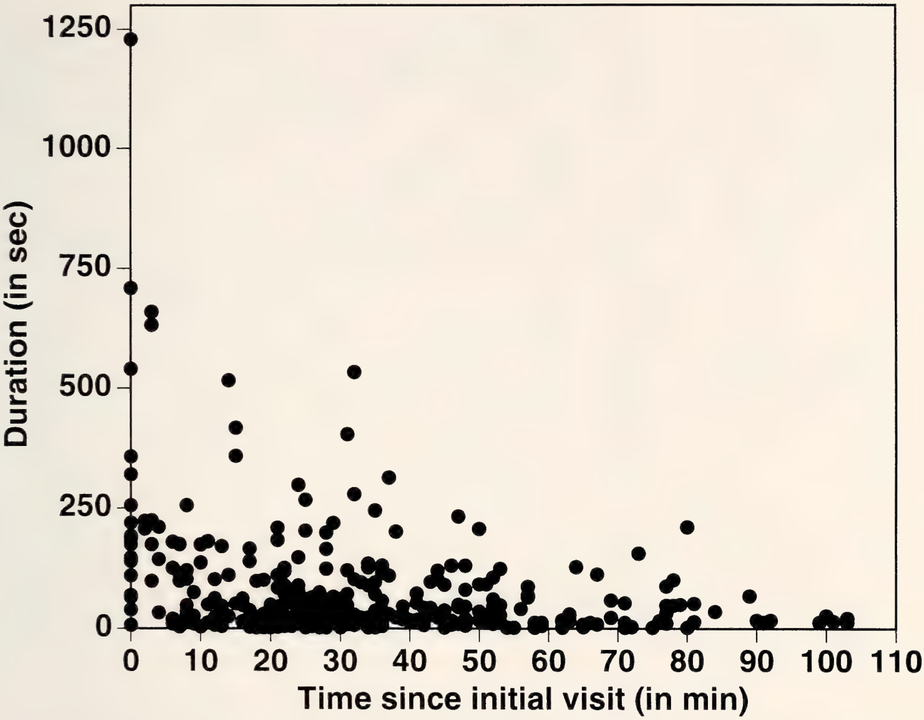

FIG. 4. Duration of pollinator visits to *Hypericum cumulicola* as mornings progressed (represented by time since initial visit since visits began at slightly different times each day). Short visits occurred all morning, but the duration of the longest visits decreased with time, presumably as pollen supplies were depleted.

DISCUSSION—*Dialictus* bees were the primary visitors to *H. cumulicola,* making 99% of all observed visits. This result is consistent with the observations of Evans and Menges (1998) who reported *Dialictus* making 81% of insect visits to *H. cumulicola.* Though we did not quantify how bees approached flowers, it was interesting to observe that most bees approached a flower by landing on a petal and then climbing onto the column of anthers, brushing the stigmas in the process. Since *Dialictus* bees are likely to be carrying pollen from other conspecific flowers upon arrival, the bent stigmas of *H. cumulicola* are likely a mechanism favoring outcrossing (or at least geitonogamy).

The duration of visits by *Dialictus* bees decreased as morning progressed, presumably because pollen supplies were being depleted and foraging became less profitable. The fact that *Dialictus* bees collect pollen to mass-provision their eggs for larval development (Deyrup, 1996) supports this presumption.

We expected that if pollinators visited *H. cumulicola* populations via trapline foraging, then populations with a short-term history of high flower density (as indicated at the end of the season by greater fruiting plant den-

TABLE 2. Relative strengths of direct, indirect, and total effects of predictor variables on each other and pollinator visitation rate to *H. cumulicola*.[a]

	Fruiting plant density			Flower density			Visitation rate		
Predictor	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
Time since last fire	−0.22	—	−0.22	−0.47	−0.10	−0.57	−0.02	−0.25	−0.27
Fruiting plant density	—	—	—	0.44	—	0.44	−0.49	0.28	−0.21
Flower density	—	—	—	—	—	—	0.64	—	0.64
U		0.97			0.70			0.83	
R^2		0.05			0.50			0.32	

[a] Direct effects are path coefficients. U, unmeasured causes; —, no interaction.

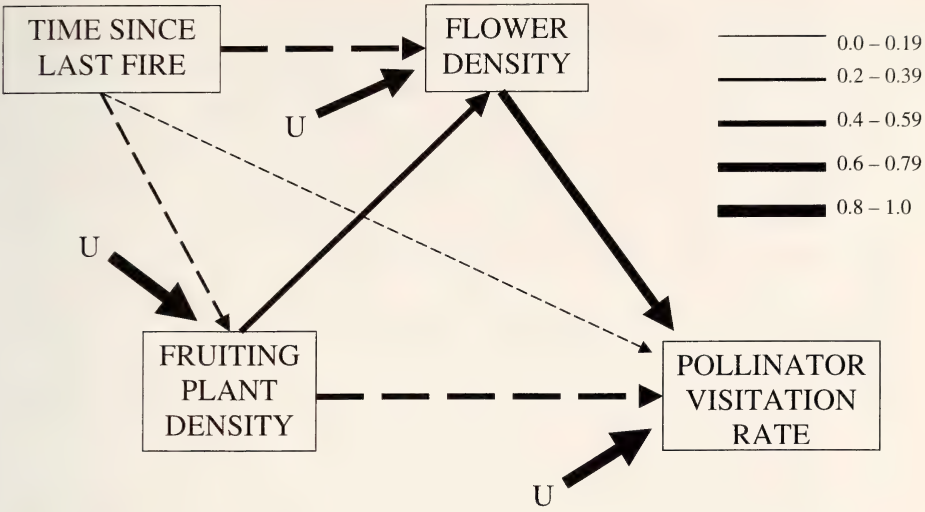

FIG. 5. Path diagram showing relationships between time since last fire, flower density, fruiting plant density, and pollinator visitation rate to *Hypericum cumulicola*. The thickness of the lines reflects the magnitude of path coefficients. Solid lines indicate positive effects and dashed lines are negative effects. U = unmeasured causes.

sity) should receive disproportionately high rates of visitation. Since pollinator visitation rate decreased with increasing fruiting plant density, it seems unlikely that pollinators trapline among populations. These ground-nesting bees probably stay primarily in their home patch, faithfully visiting all flowers. This hypothesis is also supported by genetic data that indicate a high degree of genetic differentiation and almost no gene flow among patches of *H. cumulicola* (Dolan et al., 1999). A more conclusive test of this hypothesis must include tracking of individual bees and remains a subject for future research.

Recent fire increases plant and flower densities, which, in turn, tend to increase pollinator visitation rate to *H. cumulicola.* Since seed set is directly affected by pollinator visitation rate, long unburned, isolated patches of *H. cumulicola* have decreased fecundity. These patches are likely more susceptible to additional forms of inbreeding depression due to the compound effects of few potential mates and low pollinator visitation rates. Successful preservation of this endangered species must include active prescribed burning that will maintain sufficient *H. cumulicola* densities to ensure ample pollinator service and high fecundity.

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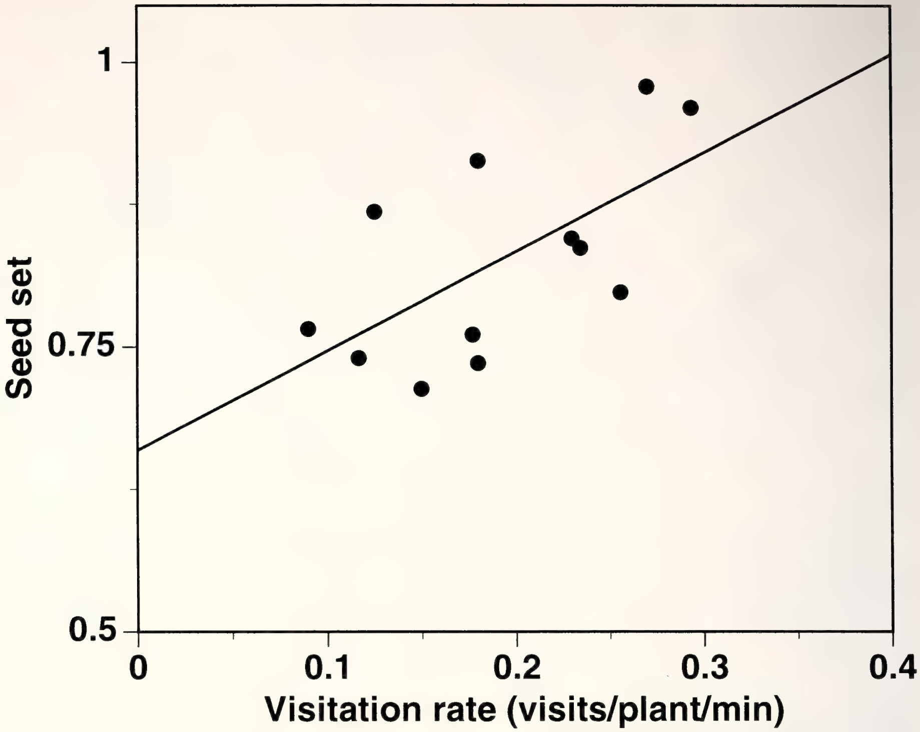

FIG. 6. The effect of pollinator visitation rate on average seed set in populations of *Hypericum cumulicola*. The proportion of seeds developed increased with pollinator visitation rate ($n = 12$; $r^2 = 0.40$; $P < 0.05$).

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EFFECT OF LIPOPOLYSACCHARIDE, CARRAGEENIN, AND DEXTRAN SULFATE ON MOUSE PERITONEAL NEUTROPHIL OXIDATIVE BURST ACTIVITY

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ABSTRACT: *The Nitroblue Tetrazolium Reduction Test (NBT) was used to analyze mouse peritoneal neutrophils for* in vitro *oxidative burst activity. Neutrophils were collected from BALB/c ByJ mice following thioglycollate challenge, washed and re-suspended in Hanks Balanced Salt Solution. Neutrophils were exposed to* 1×10^{-1}, 1×10^{-5}, 1×10^{-10}, 1×10^{-15}, *and* 1×10^{-20} *g/ml concentrations of lipopolysaccharide, carrageenin, or dextran sulfate,* in vitro, *and evaluated for changes in oxidative burst reactions. Different concentrations of challenge agents were compared to non-treated saline controls. Results demonstrated that the agents produced significant (20–90%) increases of formazan-containing neutrophils in a concentration-dependent fashion. These findings show that mouse peritoneal neutrophils can be used to study cell oxidative burst activity due to exposure to compounds released by infectious organisms.*

IN VITRO stimulation of neutrophil activity has been accomplished using many different agents ranging from bacterial and fungal antigens (Freeman and King, 1972; Gifford and Malawista, 1972; Matula and Paterson, 1971; Park et al., 1968) to components of physiological processes (Belcher and Czarnetzki, 1973; Bjorksten, 1974; Gordon et al., 1975; Rothwell and Dumas, 1975), latex particles (Baehner and Nathan, 1968; Wenger and Bole, 1973), or even laboratory glassware (Gifford and Malawista, 1972). These agents can activate neutrophils to form intracytoplasmic deposits of formazan, as assayed by the NBT test. Blood from normal humans, without defects in the immune system, have been assayed using the NBT test, and respond by having an increased percentage of formazan containing neutrophils. The type of microorganism and the intensity of an infection also have been shown to affect the numbers of neutrophils that react.

In our present study, we investigated the use of three known challenge agents on the oxidative burst activity of peritoneal neutrophils from laboratory mice to determine if this system can be used to study the inflammatory process. Neutrophils were treated, *in vitro,* with varying quantities of lipopolysaccharide, carrageenin, or dextran sulfate and assayed for oxidative burst activity using the NBT test. All three agents produced concentration dependent-increases in neutrophil formazan deposits demonstrating that mouse peritoneal neutrophils can be used to quantitatively measure the effect of different compounds on oxidative burst activity.

MATERIALS AND METHODS—*Animals*—Male, BALB/c ByJ mice were purchased from the Jackson Laboratory, Bar Harbor Maine. All mice were 90-days-old and weighed approximately 29 grams when used for experimentation.

Challenge agents—Lipopolysaccharide (from *Salmonella typhimurium*), carrageenin (from seaweed), and dextran sulfate (mwt 500,000) were purchased from Sigma Chemical Company, St. Louis, Missouri.

Neutrophil preparations—Mice were given intraperitoneal injections of thioglycollate suspensions, 1.0 mg/g body weight, and were sacrificed by cervical dislocation 12 hrs after challenge. Peritoneal cavities were lavaged using sterile cold phosphate buffered saline and cell suspensions were removed, placed in an ice bath, and cells from 3 mice were pooled and centrifuged for 10 minutes at 100 rpm at 15 degrees Centigrade. Supernatant fluid was decanted and cells were re-suspended in 10 ml of HBSS and centrifuged a second time. Following the second centrifugation, total cell counts were determined using a hemocytometer, by adding 0.9 ml of Turk's stain to 0.1 ml of cellular fluid. Wright-stained slide preparations of cells were analyzed to determine the percentage of neutrophils present (Laubach, 1985). Cell suspensions containing more than 98% neutrophils were used in the studies. Total neutrophil counts were obtained by counting 300 cells, converting the number to percent neutrophils, multiplying by the total cells present in 1.0 ml of fluid and were recorded as number of cells per milliliter of peritoneal fluid.

Nitroblue-tetrazolium test—Cell suspensions were adjusted using HBSS to provide a solution of 5×10^{6} neutrophils/ml. Glass slides were placed into large Petri dishes and 0.2 ml of cell suspensions were mixed on slides with 0.05 ml of PBS containing 1×10^{-1}, 1×10^{-5}, 1×10^{10}, 1×10^{-15}, and 1×10^{-20} g/ml of challenge agents. The Petri dishes containing slides with cell suspensions were placed into a 5% CO_2 incubator at 37° C, and left for 60 minutes. The NBT solution was then prepared by mixing 0.01 g NBT with 10 ml of PBS in a covered test tube to protect it from light. After incubation, the slide preparations were mixed with 0.1 ml of NBT solution and incubated at 37 degrees C in Petri dishes in the CO_2 incubator for 30 minutes. Next the slides were removed and the fluid was poured from each slide, gently rinsed with HBSS, and allowed to dry at 40 degrees C on a slide warmer. Cells were treated with 4% formalin/PBS for 5 min at room temperature and rinsed by dipping in distilled water. Each smear was stained for 20 min with a 0.01% safranin/10% acetic acid mixture at room temperature, rinsed with distilled water, and dried at 40° C on the slide warmer. Neutrophils were observed for large formazan granules at 1000x using a light microscope and 300 cells were counted to give the percentage of cells containing granules.

Statistical analysis—Each experiment was performed four times to determine an average and standard deviation of formazan granule containing cells. Mean values of treated cells were compared to the untreated control cells using the Student *t*-test (Snedecor and Cochran, 1972). Here, $P < 0.01$ was considered significant.

RESULTS—As shown in Figure 1, lipopolysaccharide, carrageenin, and dextran sulfate produced responses in neutrophils that were dependent on the amount of each agent used to challenge the cells. Increased amounts of each agent resulted in an increase in the oxidative burst reactions of the neutrophils, as compared to saline controls. Concentrations of 10^{-1} to 10^{-20}

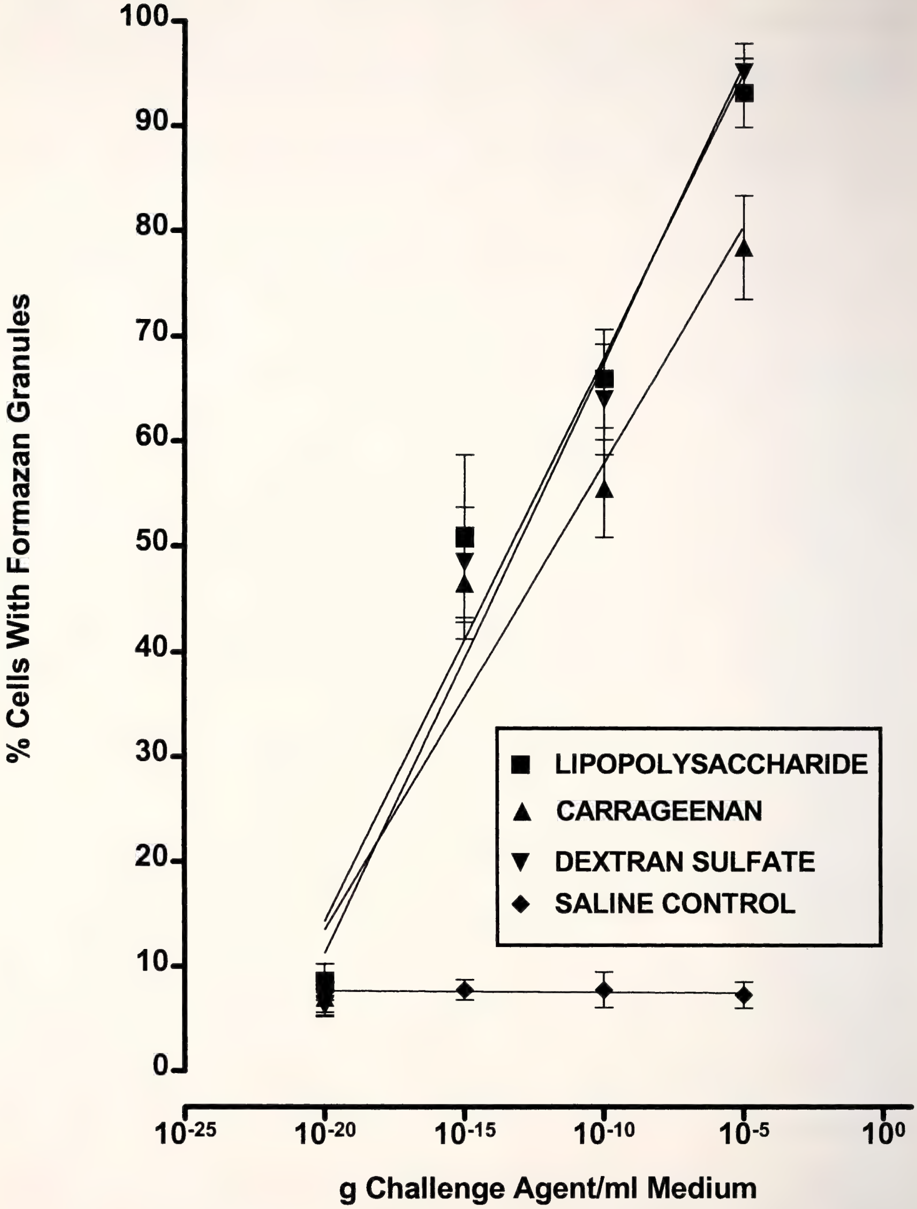

FIG. 1. Effects of various challenge agents on mouse peritoneal neutrophils. Each value represents the mean ± 1 SD of 4 experiments. Agents were examined for oxidative burst activity of mouse peritoneal neutrophils, *in vitro,* using the NBT test.

g/ml of each challenge agent resulted in significantly enhanced cell responses that decreased with decreasing amounts of the agents. The 5 to 10% readings of the saline controls were possibly due to the cell collection process where neutrophils, attracted in vivo using thioglycollate, could have been partially stimulated prior to experimentation. The overall size of the formazan formations in each cell was observed to also decrease with decreasing amounts of each agent.

Of the three challenge agents tested, lipopolysaccharide and dextran sulfate produced slightly higher activity than carrageenin, but were not different statistically. Different levels of activity associated with the challenge agents were possibly due to the numbers of chemical receptors on the neutrophils and may also relate to the effectiveness of each agent to produce the oxidative burst response.

DISCUSSION—Neutrophils play an essential role in host defense as evidenced by their response to infections and by the increased severity of infections when the numbers or activities of neutrophils are reduced. One of the important killing mechanisms of neutrophils involved in the response to infections is their oxidative burst activity. The oxidative burst response of human and rat neutrophils increases with increased amounts of lipopolysaccharide suggesting that other challenge agents as well may produce this response. The present study was thus designed to determine if mouse peritoneal neutrophils could also be used to observe increased oxidative burst responses to various challenge agents, a process indicative of a cellular reaction to infectious disease.

Three agents known to alter neutrophil activity were chosen in this study. The first was lipopolysaccharide. Effects of lipopolysaccharide (a standard in the NBT test) on neutrophil activation have been extensively used in human studies. Two recent articles clearly demonstrated that neutrophils obtained from human blood and treated with lipopolysaccharide, have enhanced oxidative burst activity (Lynn et al., 1991; Qing et al., 1996). The second, carrageenin, has been shown to enhance neutrophil migration in rats (Moraes et al., 1993; Nakagawa et al., 1992; Ogino et al., 1996; Souza et al., 1994) and in mice (Garrelly et al., 1991), to increase the production of nitric oxide in rats and mice (Tavares-Murta et al., 1996), and to inhibit the adhesion of human neutrophils (Skinner et al., 1991). The third, dextran sulfate, will block the adhesion of neutrophils to the endothelium of humans (Buttrum et al., 1993; Skinner et al., 1991) and of rabbits (Van Osselaer and Herman, 1993), and inhibit adsorption of HIV to CD4+ cells in humans (Lederman et al., 1989). Dextran sulfate also enhances neutrophil migration (Moraes et al., 1993) and stimulates neutrophil induction of colonic damage in rats (Domek et al., 1995). These previously observed changes in cellular activity produced by lipopolysaccharide, carrageenin, and dextran sulfate served as a basis to use them to compare mouse neutrophil oxidative burst activity.

Our study concludes that mouse peritoneal neutrophils are affected by *in vitro* treatment with lipopolysaccharide, carrageenin, or dextran sulfate. The enhancement of the oxidative burst response by these agents, in a concentration-dependent fashion, provides a model to systematically study the effects of other challenge components on mouse peritoneal neutrophil activity. This technique can be used to quantify the numbers of receptors for disease agents that are located on neutrophils and when they are expressed during the inflammatory process. It would reveal cell surface changes that occur during the maturation of neutrophil activation as the immune system is exposed to various disease agents.

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A COMPARATIVE STUDY OF DIGESTIVE FUNCTION IN THREE SPECIES OF HEMIDACTYLINE GECKOS FROM FLORIDA

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Abstract: *Several aspects of digestive function (digestive and assimilation efficiencies, DE and AE, and rate of gastric evacuation) were examined in three species of hemidactyline geckos from Florida:* Hemidactylus turcicus, H. garnotii *and* H. mabouia. *The DE and AE values for* H. mabouia *were significantly higher (88.4 and 75.8%, respectively) than those recorded for* H. turcicus *(80.7 and 67.2%) and* H. garnotii *(78.4 and 68.4%).* Hemidactylus mabouia *also exhibited a higher rate of gastric evacuation than the other two species. Forty-eight hr after feeding, the percent gastric evacuation for* H. mabouia *was 92.5% whereas the values for* H. turcicus *and* H. garnotii *were 75.6% and 70.4%, respectively. Differential values of DE and AE revealed in this study could provide a competitive advantage to* H. mabouia *and provide a mechanism for its superior colonization success over its two congeners in Florida.*

Several exotic species of hemidactyline geckos have successfully colonized a number of habitats in southern Florida (Meshaka et al., 2000). The Mediterranean Gecko, *Hemidactylus turcicus* Linnaeus was introduced into the United States less than a century ago, and was first recorded from Florida on Key West by Fowler (1915). It was first discovered near the Miami area in 1936 (Barbour, 1936) and was subsequently collected on the University of Florida campus in Gainesville (King, 1958). Through human intervention, *H. turcicus* has spread throughout the Gulf coastal states (Punzo, 2000a) and as far west as El Paso, Texas (Selcer, 1986) and Benson, Arizona (Robinson and Romack, 1973). More recently, the parthenogenetic Indo-Pacific Gecko *H. garnotii* Dumeril and Bibron (Indo-Pacific Gecko) appears to have replaced *H. turcicus* in southern Florida, and the bisexual Tropical House Gecko *H. mabouia* Linnaeus is now more common than *H. garnotii* (Meshaka, 1995; Butterfield et al., 1997). In turn, *H. mabouia* rapidly replaced *H. garnotii* on buildings and with more individuals (Meshaka, 2000).

Although various aspects of the natural history (Selcer, 1986; Lawson et al., 1991; Punzo, 2000a), ecology (Rose and Barbour, 1968; Selcer, 1986; Klawinski et al., 1994; Meshaka, 1995; Petren and Case, 1996; Saenz, 1996; Meshaka et al., 2000; Punzo, 2000a), and behavior (Frankenburg, 1982a, b; Bolger and Case, 1992; Vaughn et al., 1996; Zamprogno and Teixeira, 1998;

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Meshaka et al., 2000) of these hemidactyline geckos have been studied, few data are available concerning the energetics or digestive physiology of these lizards. Slade and co-workers (1994) studied the efficiencies of digestion and assimilation in *H. turcicus* collected from Louisiana. This kind of information is essential if we are to understand the role of lizards in the energy dynamics of ecosystems (Xiang et al., 1993). To my knowledge, no other data exist on the digestive physiology of other species of hemidactyline geckos.

The ability of an animal to ingest, digest, and assimilate the products of digestion into body tissues is of vital importance to survivorship (Withers, 1992; Punzo, 1995, 2000b). One parameter that is commonly used to assess digestive function is digestion efficiency, defined as the ratio of the digested components of food to the total amount of food consumed (Klekowski et al., 1975; Harlow et al., 1976). In this study, I compared various aspects of digestive function (digestion and assimilation efficiencies, and rate of gastric evacuation) in *H. turcicus, H. garnotii*, and *H. mabouia*.

MATERIALS AND METHODS—*Collection and maintenance of animals*—All geckos were collected manually or by noosing from the exterior walls of buildings with exterior lighting at night during May and June of 1999. *Hemidactylus turcicus* were collected on the campus of the University of Tampa (Hillsborough Co.), and ranged in size from 2.3–3.5 g (body mass), and from 44–52 mm in snout-vent length (SVL). Individuals of *H. mabouia* (3.1–4.2 g; 51–58 mm, SVL) and *H. garnotii* (2.9–4.4 g; 48–57 mm, SVL) were collected from Key West and Key Largo (Monroe Co.), respectively.

The geckos were brought back to the laboratory and housed individually in glass containers (20 cm height × 12.7 cm diam) and with water provided ad libitum. The geckos were housed under controlled conditions (27°C, 70% RH, 12L:12D photoperiod) in a Percival Model 217 environmental chamber. They were fed to satiation on a diet of crickets (*Acheta domestica*) dusted with a vitamin supplement. All statistical procedures followed those described by Sokal and Rohlf (1995).

Digestive and assimilation efficiencies—The method used was similar to that described by Slade and co-workers (1994) for their studies on digestive and assimilation efficiencies in *H. turcicus* from Louisiana, thereby facilitating direct comparisons between their data and those from this study. Ten geckos of each species were weighed on a Sartorius electronic balance (Model 87A, Central Scientific, Chicago, Illinois) to the nearest 0.01g, and SVL was determined with Vernier calipers. After being placed in their containers, they were deprived of food for an amount of time sufficient to ensure clearance of the gut (3 wk when maintained at 27°C). Each animal was subsequently fed one cricket (*A. domestica*; mean weight: 512 mg ± 8 SD) every 3 d for 70 d. The crickets were obtained from a laboratory stock culture. All of the lizards fed regularly and gained body mass over the 70 d period. The mean gain in body mass was 9.9% (SD = 4.7) for *H. turcicus*, 11.2% (SD = 5.7) for *H. mabouia*, and 10.2% (SD = 2.9) for *H. garnotii*.

To determine the water content of crickets, three samples consisting of 12 insects were dried for 24 hr at 60°C in a Boekel drying oven (Model 107801, Carolina Biological Supply, Burlington, North Carolina), then weighed on an electronic analytical balance, and the resulting mass was then subtracted from the wet mass.

Feces and solid urinary wastes were collected from the geckos after each feeding and pooled for each individual animal. Urinary wastes were separated from fecal material as described by Klekowski and Duncan (1975) and frozen separately for subsequent analyses which consisted of drying at 60°C for 24 hr, followed by homogenization, and compression into pellets. The pellets were then weighed and bombed in a Ohaus Model 2764B Bomb Calorimeter (Cole and Parmer). Crickets were analyzed in a similar fashion to determine their caloric content, as described by Prus (1975). Dry masses of lizard feces and urinary wastes, as well as crickets, were corrected for ash content by weighing the residual material remaining after each sample was bombed (Smith, 1976).

Digestion and assimilation efficiencies were determined according to the equations described by Johnson and Lillywhite (1979). Digestive efficiency (DE) represents the percent of calories in food absorbed through the gastrointestinal tract (Phillipson, 1966). The DE was calculated using the formula: $(C - F) / C \times 100$, where C represents the calories consumed, and F represents the calories of fecal waste. Assimilation efficiency (AE) is defined as the percent of usable calories retained by the animal and was calculated using the formula: $(C - (F + U)) / C \times 100$, where U represents the calories of urinary waste.

Gastric evacuation—Gastric evacuation or depletion (amount of food moved through the stomach / unit time) is considered a function of digestion and was measured by using the dry weight method described by Windell and Sarokon (1976). The amount of food evacuated from the stomach / unit time was determined by dividing the amount of dry matter remaining in the stomach at autopsy by the computed amount of dry matter ingested for each of six time intervals. Gastric evacuation experiments were conducted on a different group of geckos maintained under the same controlled laboratory conditions described above. All experiments were conducted at 27°C and 70% RH. Temperature was kept constant because rates of physiological processes in ectotherms can change significantly as a function of temperature. Geckos were deprived of food for 3 wk prior to testing to ensure clearance of the gut.

For each feeding trial a gecko was allowed to feed on one cricket (512 ± 8.0 mg). At predetermined time intervals (8, 16, 24, 32, 36, and 48 hr) following the ingestion of a cricket (weighed to the nearest 0.1 mg), samples of geckos ($N = 5$ for each temperature interval and species) were sacrificed and immediately autopsied. Stomach contents were removed, placed on an aluminum pan, and dried to a constant weight at 80°C. Data were expressed as percent gastric evacuation (Windell and Sarokon, 1976).

RESULTS—*Digestive and Assimilation Efficiencies*—The mean water content for crickets was 77.2% ($SD = 1.21$, $N = 36$). Their mean ash and caloric contents were 4.6% ($SD = 0.88$) and 5303 cal / g ($SD = 101.9$), respectively. The mass of crickets consumed, mass of feces, caloric content of feces, mass of urinary wastes, caloric content of urinary wastes, DE, and AE for *H. turcicus, H. garnotii*, and *H. mabouia* are shown in Table 1. The DE and AE for *H. mabouia* were significantly greater than those values obtained for *H. turcicus* and *H. garnotii* ($G = 7.81$, $P < 0.05$). There were no significant differences between the DE and AE values of *H. turcicus* and *H. garnotii* ($P > 0.50$).

Gastric evacuation—The percent gastric evacuation (depletion) at various time intervals for these hemidactyline geckos are shown in Fig. 1. An analysis of variance (ANOVA) indicated a significant effect of time after feeding on gastric evacuation ($F = 48.7$, $P < 0.001$). The evacuation rate for *H. mabouia* was higher at all time intervals when compared to the other two species (ANOVA, $F = 8.2$, $P > 0.05$). There was no significant difference in the evacuation rates between *H. turcicus* and *H. garnotii* ($P > 0.5$). Forty hr after feeding, the percent gastric evacuation for *H. mabouia* exceded

TABLE 1. Comparison of digestive function in three species of hemidactyline geckos (*Hemidactylus*). Data expressed as means ± SD (N = 10 for each species). CMC (total dry mass consumed, g, over the 70 d period); FM (mass of feces, g); CCF (caloric content of feces, cal/g); UWM (mass of urinary waste, g); CCUW (caloric content of urinary wastes, cal/g); DE (digestive efficiency, %); AE (assimilation efficiency, %). See text for details.

Value	*H. turcicus*	*H. garnotii*	*H. mabouia*
N	10	10	10
CMC (g)	1.04 ± 0.03	1.08 ± 0.02	1.37 ± 0.06
FM (g)	0.19 ± 0.02	0.22 ± 0.03	0.41 ± 0.05
CCF (cal/g)	3365 ± 114.6	3298 ± 83.5	3381 ± 101.8
UWM (g)	0.38 ± 0.02	0.43 ± 0.01	0.47 ± 0.03
CCUW (cal/g)	2452 ± 33.2	2471 ± 27.3	2374 ± 30.6
DE (%)	80.7 ± 3.1	78.4 ± 2.3	88.4 ± 2.9
AE (%)	67.2 ± 4.3	68.4 ± 3.6	75.8 ± 2.2

90%. This was significantly greater than that recorded for *H. turcicus* ($t = 5.1$, $P < 0.5$) and *H. garnotii* ($t = 7.7$, $P < 0.01$) which were both below 70%. *Hemidactylus mabouia* removed a greater amount of food (25%) from its stomach within a relatively short time after feeding (8 hr) as compared to *H. turcicus* (17%) and *H. garnotii* (15%).

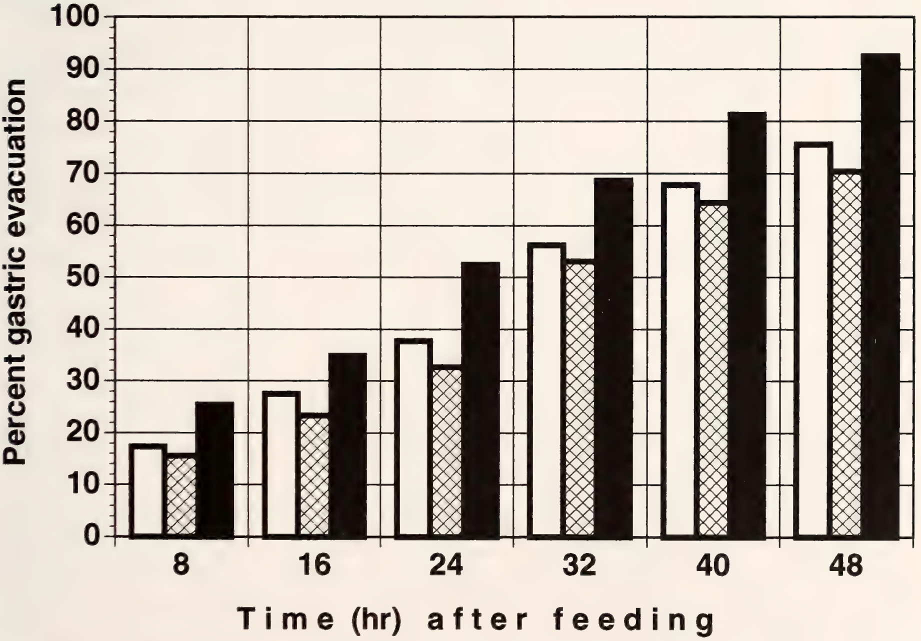

FIG. 1. Percent gastric evacuation for three species of hemidactyline geckos at various time intervals (hr) after feeding. The species were *Hemidactylus turcicus* (white bars), *H. garnotii* (hatched bars), and *H. mabouia* (black bars). See text for details.

DISCUSSION—Most of the previous work on lizard foraging energetics has focused on prey choice and the metabolic costs associated with foraging mode (Waldschmidt et al., 1987; Witz and Lawrence, 1993; Thompson and Withers, 1997). Researchers have typically attempted to predict prey choice on the basis of cost / benefit analyses, with little attention to the actual processes of digestion, absorption, and assimilation of digested products. These processes are important because the energy of material absorbed from food and available for assimilation into somatic or reproductive tissues will be less than the total amount of energy contained in the food ingested. Thus, any attempt at a cost / benefit approach would be more accurate if prey / food profitabilities were estimated from data on energy absorbed rather than the total energy content of food.

The digestive and assimilation efficiencies of *H. turcicus* from Tampa, FL (Table 1) were similar to those reported by Slade and co-workers (1994) for *H. turcicus* from Louisiana (DE = 87%; AE = 72%), and similar to values reported for other omnivorous and insectivorous lizards which range from 75–90% (DE), and 70–95% (AE) (Harwood, 1979; Ruppert, 1980; Waldschmidt et al., 1987; Witz and Lawrence, 1993; Xiang et al., 1993; Hammond and Diamond, 1997). In reptiles, DE and AE can vary as a function of the type of food eaten, age of the animal, general level of activity, and and body temperature (Windell and Sarokon, 1976; Harwood, 1979). As a result, it may be expected to vary under natural conditions where a number of different prey types are selected and the T_b of the animal changes during the period when it is foraging.

The higher DE and AE values exhibited by *H. mabouia* (Table 1), coupled with its higher gastric evacuation rate (Fig. 1), may account to some degree for the observation that this gecko appears to be replacing *H. garnotii* and *H. turcicus* in southern Florida (Meshaka, 2000; Meshaka et al., 2000). A lizard that has a higher AE can also empty its gut more rapidly, and may feed more frequently and exhibit higher growth rates than its potential competitors. This could affect some important life history traits including age and size at maturity, the number of clutches (offspring) produced / reproductive season, and size of offspring. Other factors that have been implicated in the increasing abundance of *H. mabouia* at the expense of *H. turcicus* and *H. garnotii* inlcude the potential liability associated with an increased level of aggression in the unisexual *H. garnotii*, interspecific differences in the degree of territoriality, and predation by *H. mabouia* on other geckos (Petren et al., 1993; Meshaka, 2000).

If differential values of DE and AE provide a clue to replacement mechanisms among exotic geckos, this approach can be applied to recently established exotic geckos in Florida, like *H. frenatus*, as part of a predictive framework of colonization success among members of the rapidly changing exotic gecko assemblage of Florida.

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NEUROCHEMICAL CORRELATES OF AGONISTIC INTERACTIONS AND DOMINANCE BETWEEN MALES OF THE BROWN ANOLE, *ANOLIS SAGREI*

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ABSTRACT: *Neurochemical analyses were conducted on whole brain extracts from dominant and subordinate males of the brown anole,* Anolis sagrei. *The brains of dominant males contained significantly higher concentrations of catecholamine neurotransmitters such as dopamine and norepinephrine, while exhibiting a lower level of acetylcholinesterase activity. Concentrations of the neurotransmitters, serotonin and gamma amino butyric acid, were significantly higher in the brains of subordinate males. The role of hormones and neurotransmitters in the mediation of agonistic behaviors and dominance in reptiles and other vertebrates is discussed.*

AGGRESSION between conspecific animals is inexorably associated with the ability to compete for various resources including food, mates and space (Leshner, 1983; Scott, 1984; Huntingford and Turner, 1987; Punzo, 1998). Furthermore, sexual selection theory suggests that one benefit associated with increased aggression is greater success in male-male competition for females despite the costs associated with the energy allocated to it (Thornhill and Alcock, 1983; Stearns and Hoekstra, 2000). Some have argued that the term "aggressive behaviors" should only apply to groups of behaviors that at times have no functional relationships, whereas "agonistic behaviors" refer to behaviors that are all functionally related. For example, various types of aggression have been identified such as maternal aggression, social aggression (offensive attack and sibling aggression), infanticide, cannibalism, and self-defense (Brain, 1979; Bolin and Davanzo, 1982; Frank et al., 1991). In contrast, agonistic behaviors refer to those interactions related to physical conflict between adult members of the same species such as fighting, threat displays, defensive postures, escape, dominance, subordination, and territoriality (Scott, 1966; Tokarz, 1985; Zucker and Murray, 1996; Punzo, 2000). This distinction between aggressive and agonistic behaviors will be applied throughout this paper.

Many researchers have been interested in studying the relationship between hormones and other chemical correlates of aggression or dominance. It is well known that steroid hormones strongly influence the physiology and behavior of all animals, including reptiles. Testosterone and adrenocorticosteroids, for example, have been identified as primary modulators of aggression in a wide variety of vertebrates including fish (Villars, 1983), reptiles (Adkins and Schlesinger, 1979; Tokarz, 1987; Denardo and Licht, 1993; Denardo and Sinervo, 1994; Hews et al., 1994; Knapp and Moore, 1997), birds (Harvey and Hall, 1990; Schlinger and Callard, 1990), and mammals (Frank et al., 1991; Zielinski and Vandenbergh, 1993; Blanchard and Blanchard, 1997).

Although they have been less extensively studied, several comodulators (CMs), amino acids (AA), and neurotransmitters (NTs) found in various brain regions have also been correlated with aggressive and agonistic interactions in birds (Edens, 1987; Schlinger and Callard, 1990; Silverin, 1998) and mammals (Eleftheriou and Church, 1968; Eichelman and Thoa, 1973; Stern and Catovic, 1975; Barr et al., 1979; Bolin and Davanzo, 1982; Rodgers and Depaulis, 1982; Muñoz-Blanco et al., 1986; DeVrey, 1995). However, little information on the relationship between brain chemistry and aggression or dominance is available for ectothermic vertebrates (Greenberg and Crews, 1983; Punzo, 1985; Phillips and Howes, 1988; Lance, 1990). Studies on localization of brain function in mammals and lizards have shown that various regions throughout the telencephalon, mesencephalon, and rhombencephalon are involved in the expression or inhibition of agonistic behavior and dominance (Kemble et al., 1984). In lizards these regions include the amygdaloid complex (Keating et al., 1970; Tarr, 1977), located in the posterior one third of the basal telencephalon, the anterior dorsal ventricular ridge (DVR) (Northcutt, 1967; Sugerman and Demski, 1978), tegmentum (Distel, 1977), septal and preoptic areas (Distel, 1977), the hypothalamus (Sugerman and Demski, 1978), medulla oblongata (Kennedy, 1975), and pineal complex (Phillips and Howes, 1988).

The purpose of this study was to identify neurochemical correlates of agonistic behavior and dominance in the brown anole, *Anolis sagrei*, a lizard whose social interactions with conspecifics have been described in detail (Evans, 1938; Salzburg, 1984; Scott, 1984; Tokarz, 1985, 1987; Tokarz and Beck, 1987). This successful colonizing species is commonly found in open vegetation and also utilizes perch sites from 1–2 m off the ground on the branches of bushes and trees as well as on the sides of buildings and wooden fences (Lee, 1985). *Anolis sagrei* is sexually dimorphic and polygynous. Males possess an orange-red dewlap, are strongly territorial, and defend circumscribed areas against conspecifics as well as other lizard species (Collette, 1961; Rand and Williams, 1969).

When a mature male *A. sagrei* encounters another lizard it exhibits a challenge display which consists of approaching the intruder, dewlap fanning and erection of the nuchal and dorsal crest, a sagittal expansion of the body, headbobs and/or pushups, and finally an attack which can culminate in biting (Evans, 1938; Tokarz and Beck, 1987). As a result of these challenge displays, dominant males chase intruders (subordinates) away from their perch sites. These agonistic behaviors are associated with well known changes in circulating levels of corticosteroids and testosterone as well as other neurochemical factors including AA, CMs, and NTs. In this study, I identified differences in whole brain neurochemistry associated with agonistic interactions and dominance in adult males of *A. sagrei.*

METHODS—Adult males were collected by noosing from a wooden fence (60 m in length and 2.5 m high) located in Brandon, FL (Hillsborough County), in 1998, between 20 May and 15 June, when males were reproductively active. Social interactions between various individuals were easy to observe on this fence since they were frequently out in the open, and males exhibited a high degree of site fidelity (pers. observ.). Males attain sexual maturity at a snout-vent length (SVL) of > 39 mm (Licht and Gorman, 1970). Since it has been demonstrated that male body size is an important determinant of dominance in *A. sagrei* (Tokarz, 1985), only males of similar size were used in this study (mean SVL: 51.0 mm ± 0.3 SEM).

Each anole was given a distinctive toe clip mark to allow subsequent identification and released at its original capture site. I observed frequent challenge displays when intruders would approach a territorial male. Males were categorized as either dominant or subordinate on the basis of these encounters. Any male that exhibited a challenge display and successfully chased a different intruder away from its perch site on 10 consecutive occasions was considered a dominant male. Males that were driven away from a dominant males' perch site on 10 consecutive occasions were designated as subordinate males.

After establishing their dominance status, 20 dominant and 20 subordinate lizards were recaptured, sacrificed, stored on dry ice and returned to the laboratory where they were kept in a freezer (− 20°C) and later thawed for subsequent neurochemical analyses.

Whole brains were removed and weighed on a Sartorius Model 54C electronic analytical balance. Individual brain extracts were assayed for several NTs including norepinephrine (NE), dopamine (DA), 5-hydroxytryptamine (5-HT, serotonin), and gamma amino butyric acid (GABA), as well as for acetylcholinesterase (AChE).

Brain NE and DA were isolated on aluminum hydroxide following the protocol of Anton and Sayer (1962). DA was analyzed using the cation exchange method described by Barchas and co-workers (1972) and expressed as μg / g. NE (μg / g) was determined fluorometrically according to the procedure of von Euler and Lishajko (1961). GABA was analyzed by the enzymatic GABASE protocol (Sigma Chemical Co., St. Louis, MO) as described by Davanzo and Sydow (1979) and expressed as nmol / mg. Serotonin (μg / g) levels were estimated according to the method of Bogdanski and co-workers (1956). AChE activity was determined using the method reported by Willner and Mellanby (1974) and Punzo (1988) and expressed as μmol of acetylcholine (ACh) hydrolyzed / hr / g. Differences between the concentrations of these various compounds in brains of dominant and subordinate anoles were tested for significance using t—tests (Sokal and Rohlf, 1995).

RESULTS AND DISCUSSION—The brains of dominant males of *A. sagrei* contained significantly higher concentrations of DA, NE, as well as AChE activity, and lower concentrations of 5-HT and GABA (Table 1). This is in general agreement with results reported for birds (Edens, 1987; Harvey and Hall, 1990; Schlinger and Callard, 1990) and mammals (Eichelman and Thoa, 1973; Arnt and Scheel-Kruger, 1979; Bolin and Davanzo, 1982; Muñoz-Blanco et al., 1986; Reis, 1994).

The relationship between NE, DA, and agonistic behaviors has been well established in birds and mammals. In birds, for example, Marley (1983) showed that aggression could actually be induced in chickens given NE uptake inhibitors which resulted in elevating NE concentrations at post-syn-

TABLE 1. Concentrations of neurotransmitters and acetylcholinesterase found in whole brain extracts from dominant (N = 20) and subordinate (N = 20) males of the brown anole, *Anolis sagrei*. Values represent means (± S.D.). DA (dopamine); NE (norepinephrine); 5-HT (5-hydroxytryptamine, serotonin); GABA (gamma amino butyric acid); AChE (acetylcholinesterase). See text for details.

	Concentration		
Compound	Dominant	Subordinate	p
DA (μg/g)	0.987 (± 0.07)	0.744 (± 0.06)	$p < 0.05$
NE (μg/g)	1.182 (± 0.21)	0.833 (± 0.08)	$p < 0.05$
5-HT (μg/g)	0.447 (± 0.03)	0.578 (± 0.02)	$p < 0.05$
GABA (nmol/mg)	17.76 (± 2.5)	22.18 (± 3.4)	$p < 0.01$
AChE[a]	0.633 (± 0.05)	0.522 (± 0.02)	$p < 0.05$

[a] AChE activity expressed as μmol of ACh hydrolyzed/hr/g.

aptic sites. Aggressive pecking was enhanced in Japanese quail given noradrenergic and dopaminergic agonists (Duchala et al., 1994).

Despite some conflicting results, norepinephrine and DA are thought to play an important role in the mediation of aggression and dominance in mammals as well. For example, intraspecific fighting between male Norway rats in laboratory staged encounters is associated with elevated DA and NE concentrations in the hypothalamus and amygdala of dominant animals (Barr et al., 1979; Blanchard and Blanchard, 1997), although no comparable differences were reported for dominant vs. submissive individuals in several strains of laboratory mice (Avis, 1974; Bernard et al., 1975). What is difficult to assess in these kinds of studies is whether or not any differences in neurochemical parameters between winners and losers is due to a genetic predisposition toward aggression, or can be attributed to alterations in brain chemistry caused by the experience of fighting. Nevertheless, the results of this study on agonistic interactions between male brown anoles under natural conditions indicate that dominance in reptiles is also associated with similar differences in neurochemical parameters.

The brains of dominant males of *A. sagrei* had significantly lower levels of GABA (Table 1) which is considered to be a universal inhibitory NT (Valzelli, 1991; Punzo, 1996). Microinjections of GABA have been shown to inhibit aggressive responses in cats (Brody et al., 1969). Early and Leonard (1977) reported that aggressive mice had lower GABA levels than non-aggressive animals in several brain areas including the striate cortex and olfactory bulb. Increased muricidal behavior in rats is also associated with lower regional brain GABA levels in the amygdala, hypothalamus, olfactory bulbs, and other areas of the limbic system (Bolin and Davanzo, 1982). GABA levels were significantly lower in the brains of aggressive fighting-bulls when compared with non-aggressive strains (Muñoz-Blanco et al., 1986). It appears that increased levels of GABA have a dampening effect on agonistic behaviors in *A. sagrei* and other vertebrates.

Brain serotonin (5-HT) levels were higher in subordinate males of *A* *sagrei* (Table 1). This is interesting in light of studies that have documented increased levels of serotonin in various brain regions after five days of exposure to fighting and defeat in mice (Eleftheriou and Church, 1968; DeVrey, 1995) and rats (Sanford et al., 1995). It is not known how many times the subordinate males of *A. sagrei* may have been "defeated" by resident males before the initiation of this study. Nonetheless, subordinate anoles were characterized by significantly lower concentrations of serotonin, suggesting that reduced levels of this indolalkylamine NT may be associated with heightened aggression and dominance in reptiles. In contrast, increased aggression was associated with higher levels of serotonin in the brains of social insects (Brandes et al., 1990) as well as those of the solifugid *Eremobates palpisetulosus* (Arthropoda, Arachnida, Solifugae) (Punzo, 1994), suggesting that this NT may function in different ways among various taxonomic groups.

Dominant males of *A. sagrei* exhibited significantly higher levels of AChE activity (Table 1). The only other study that looked at AChE activity and agonistic behavior reported an increase in this enzyme in the brains of resident birds but not in intruders (Edens, 1987). Although reduced AChE activity is associated with higher associative functions such as learning and memory in both vertebrates (Ungar, 1972) and arthropods (Punzo, 1996), the relationship between brain concentrations of AChE and aggression is not clear at this time.

In summary, aggressive and agonistic interactions, as well as dominance, are comprised of different and complex behavioral patterns, each with its own neuronal, neurochemical and endocrine basis. The prevailing view is that there is no uniform neurobiological / neurochemical substrate for aggression in the general sense, and that different aggressive responses are under the control of various hormones, NTs, and CMs, which most likely interact in various ways. However, there are certain endocrine and neurochemical mechanisms that seem to be common to many different behavioral types of aggression and dominance including testosterone, corticosterone, DA, NE, 5-HT, and GABA. These have been demonstrated in birds and mammals, and the results of this study extend some of these findings to reptiles.

Future studies should focus on other species of reptiles as well as amphibians and fish. In addition, neurochemical analyses should be conducted separately on specific brain regions including the hypothalamus, corpus striatum, dorsal ventricular ridge, tegmentum, and amygdaloid complex, to determine if there are subtle differences in brain chemistry between dominant vs. subordinate animals in these regions.

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SOME SOIL PROPERTIES AND PLANT RELATIONSHIPS IN MARSHES OF THE SUWANNEE RIVER DELTA

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ABSTRACT: *We made this study with the objective of establishing parameters which could be used to determine minimum Suwannee River flows at which significant damage would occur to the environment. Significant damage is defined as that level of degradation of the environment beyond which the system will not be able to return to its former healthy state. We inventoried plant species distribution in the marsh, determined some characteristics of the soils, and measured water salinity. We found many more species of plants in the marshes of the Suwannee delta than is common in tidal marshes distant from fresh water. Some of these plants are highly salt tolerant such as* Distichlis spicata *(L.) Greene (saltgrass) and* Juncus roemerianus *Scheele (needlerush). Some have less salt tolerance i.e.* Sagittaria lancifolia *L. (arrowhead) and* Scirpus americanus *Pers. (three-square). The soils are high organic mineral soils or organic soils (> 30% organic matter), anoxic, and contain high amounts of sulfur. Soil salinity, measured by electrical conductivity (EC) is higher near the Gulf and decreases as one goes upriver. There is little significant correlation between soil EC and the distribution of most plants. Although saltgrass and needlerush are very common in the areas of highest EC, the generally low salinity levels permit the growth of a variety of plants. Another phenomenon resulting in erratic distribution of plants is wrack, plant debris deposited by storms over existing vegetation, resulting in the death of the original plants and the invasion or expansion by opportunistic species. Low rainfall and low river flow in June, 2000 resulted in an increase in soil water EC of 17% to 142% and damage to several plant species in the Delta.*

THE Suwannee River heads in the Okefenokee Swamp in southeast Georgia and north Florida and flows 381 km (237 miles) south and southwest to empty into the Gulf of Mexico just below the village of Suwannee. The mean flow at the mouth is 26,838 metric liters per day (7,100 million gallons per day) and ranges from 20,075 to 87,858 mld (5,311 to 23,2543 mgd) (Fernald and Patton, 1984). The river mouth is comprised of two outlets, West Pass and East Pass, with West Pass carrying about 60% of the flow. It is the second largest river in the state. The Apalachicola River has about 10 times this discharge.

River chemistry and quality change appreciably from source to mouth (Fernald and Patton, 1984). Acidity decreases from a pH of 4 at Fargo, GA to over 6 at Branford, FL. Total organic C decreases appreciably below White Springs and nitrate levels increase. This increase in nitrate levels, probably because of an increase in dairy and poultry operations, is becoming more of a health problem in the watershed (Mattson, 1999).

The delta of the River is approximately 6 km wide and varies from 1.6

to 3.2 km in depth, where covered by herbaceous tidal marsh plants. It is part of the Lower Suwannee National Wildlife Refuge. The delta is highly dissected with tidal creeks, many of which are interconnected at high tide. The soils are nearly flat (0–1%) except for an area of upland west of Hog Island Creek and two or three other areas to the east of East Pass. The rainfall at Cross City, FL (approx. 37 km south of the study area) averages 144 cm (56.7 inches) with November being the driest month and July the wettest (Fernald and Patton, 1984). January is the coldest month 11.7°C (53°F) and August the warmest 26.7°C (80°F). Rainfall is slightly lower at Cedar Key (15 km southwest of study area).

The predominant marsh vegetation is the salt tolerant *Juncus roemerianus* Scheele (needlerush) and the less tolerant *Cladium jamaicense* Crantz (sawgrass). *Distichlis spicata* (L.) Greene, a highly salt tolerant grass, is locally common. Less salt tolerant species in the genera *Sagittaria* and *Scirpus* are also common. On the berms, *Taxodium* spp. (cypress), *Fraxinus profunda* (Bush) Bush (pumpkin ash), *Myrica cerifera* L. (wax myrtle), *Sabal palmetto* Lodd. ex J. S. Shult. & J. H. Shult. (cabbage palm) and *Persea palustris* (Raf.) Sarg.(swamp bay) occur sporadically (Clewell et al., 1999).

The marsh is bordered on the north by stunted ash trees with an understory of sawgrass. Soil surveys of the marsh have been completed or are in process (USDA, 1996a; USDA, 1999). The portion west of East Pass was mapped as Wulfert muck, a Sulfihemist, and the eastern portion as Tidewater mucky clay, a Sulfaquent. The swamp portion of the delta was mapped as Yellowjacket and Maurepas muck, both Medisaprists.

Serious erosion is evident along the shoreline facing the Gulf. The U.S. Corps of Engineers installed a concrete monument in 1977, 24 meters from the shoreline near Mitchell Creek. This monument was exposed to the sea in 1997 indicating a loss of 24 m of marsh in 20 years. There was little evidence of serious erosion along river channels and tidal creeks, however, there was evidence of erosion in the lower reaches of the river swamp. Small "islands" of *Juniperus virginiana* L. (red cedar), cabbage palm, and cypress were abruptly higher than the flats, which were sparsely vegetated with ash, *Acer rubrum* L. (red maple) and herbaceous plants. This erosion was probably due to storm events and rising sea level.

The objective of this research was to determine certain soil properties, plants and their distribution, and possible correlations between them. This will provide base-line data to assist the Suwannee Water Management District determine minimum flow levels at which significant environmental damage may occur.

METHODS—We laid out transects, 121.6 to 182.4 m long (400 to 600 ft), perpendicular to the River near its mouth and upstream near the tidal swamps (Fig. 1). We also installed transects on two tidal creeks which were not directly affected by river flow. Relative elevation was determined with a dumpy level. We sampled the soils at 30.4 m (100 foot) intervals along the transect and described them according to Soil Survey Manual procedures (USDA, 1993). We

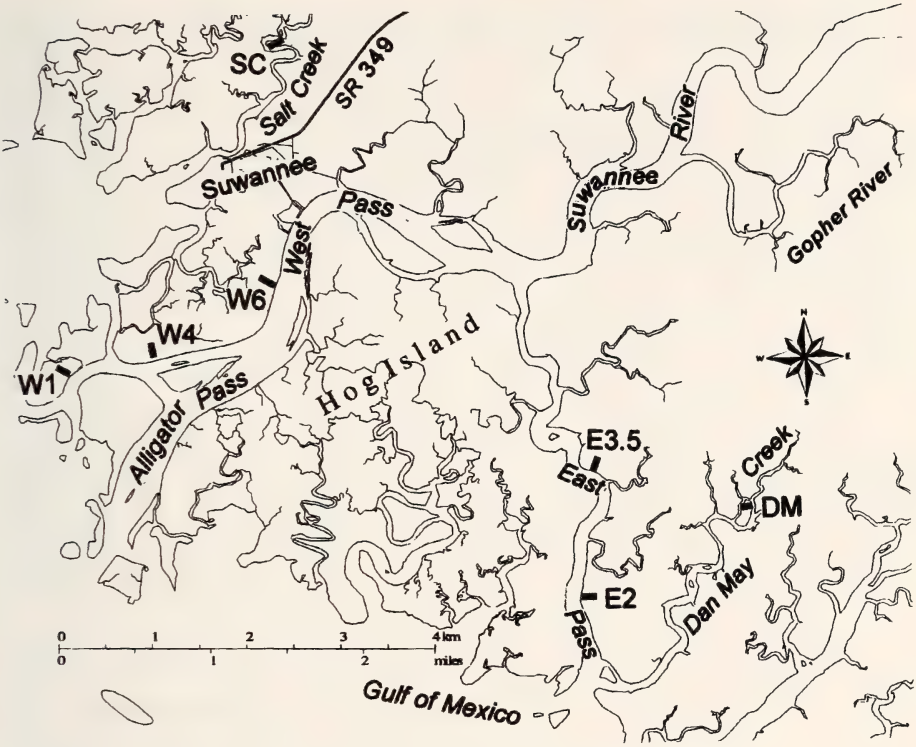

FIG. 1. Permanent transect locations at the delta of the Suwannee River.

also determined vegetation at these and other sites (Clewell et al., 1999). Some soil properties and vegetation were determined over an 18-month period. Organic matter was determined by low temperature ignition (Jackson, 1958). For pedon descriptions and analyses we sampled to a depth of 122 cm. Bulk density was determined by two methods: 1) A bucket auger, 17.8 cm by 7.6 cm, was used to extract a surface soil sample. This hole was lined with a plastic bag and its volume determined by filling it with water. 2) A sharpened PVC cylinder with a volume of 997 cm^3 was inserted into the subsoil and extracted. In both methods the soil removed was oven-dried, weighed, and its bulk density calculated.

Particle-size determinations were attempted following the Bouyoucous method (Day, 1965). We boiled the soil samples in 1.5% sodium hypochlorite (2 successive treatments of 30 mL), treated them overnight with 100 mL of 5% sodium hexametaphosphate, and mixed the suspension in a blender for 2 minutes. Some original organic matter remained. We then washed the treated soil on a 270-mesh sieve, dried, and weighed the sands that were retained. Organic matter was determined using a low-temperature ignition procedure (Jackson, 1958).

Rods for measuring the oxidation-reduction potential of the soil were prepared by welding 1 cm of platinum wire to a 45 cm long #12 copper wire. The connection was then fully insulated with epoxy (Patrick et al., 1996). The rods were calibrated in a quinhydron solution and inserted into the soil to a depth of 10 cm and 30 cm. The redox potential was measured in millivolts using a portable Orion Model 250-A pH/ISE meter.

We determined electrical conductivity (EC) on the saturated soil extract (USDA, 1954) without previous drying. We sampled soils from the riverbank (or tidal creek) at 30.4 m (100 ft) intervals at 2 depths, 5–25 cm and 61–81 cm to include soil both in the root zone and below it. We used a Hanna HI 9033 meter to determine EC. We used this same sample (before liquid extraction) to measure pH with an Orion Model 250 pH/ISE meter. To determine the presence of sulfidic horizons we followed a standard aerobic incubation procedure (USDA, 1996b)

RESULTS AND DISCUSSION—The locations of the sampling sites in the tidal marshes of the Suwannee River delta are shown in Fig. 1. The vast majority of the soils in the intertidal marshes of the Suwannee River delta are either high organic mineral soils or organic soils (Table 1). Most soils are very dark grayish-brown in color (10YR 3/2) or very dark gray (10YR 3/1) in the surface and subsoil. The soils on the lower reaches of West Pass (W1) are interstratified layers of organic material, mucky sand and mucky sandy clay loam. Sand sometimes occurs below 107 cm (42 inches). As one goes upstream on West Pass (W4, W6) most of the soils are organic.

Near the mouth of East Pass, most soils are mucky sand or mucky sandy loam in texture. Organic matter ranges from 8.4% to 38.5% (Clewell et al., 1999). Upriver the soil at the berm (E3.5–44′) is a mineral soil with sandy loam and sandy clay loam textures and is lighter colored (dark gray and light gray) than most other soils. Organic matter ranges from 11.7% at the surface to 2.2% in the subsoil. As one goes inland from the River the soils

TABLE 1. Organic matter content, sand distribution, estimated texture, color and bulk density for selected soils along permanent transects.*

Location	Depth (cm)	Organic matter (%)	Sand (%)	Munsell Color	Estimated texture	Bulk density g/cm^3
W1-200	0–20	32.2		10 YR 2/2	organic	0.2
	20–48	19.2	78.2	10 YR 3/3	mucky sandy loam	
	48–58	25.1	58.7	10 YR 3/2	mucky sandy clay loam	0.2
	58–117	21.2	65.9	10 YR 3/3	mucky sandy clay loam	
W4-300	0–20	35.5		10 YR 3/1	organic	0.1
	20–38	45.3		10 YR 3/2	organic	
	38–61	56.3		10 YR 3/2	organic	
	61–104	39.2		10 YR 3/1	organic	0.1
W6-200	0–20	53.0		10 YR 3/1	organic	
	20–61	53.8		10 YR 3/2	organic	
	61–122	45.5		10 YR 3/1	organic	0.2
E2-188	0–20	22.1	83.0	10 YR 3/2	mucky sandy loam	0.2
	20–61	19.5	80.1	10 YR 3/2	mucky sandy loam	
	61-122	17.8	86.3	10 YR 3/2	mucky loamy sand	
E3.5–200	0–25	25.2	77.0	10 YR 3/2	mucky sandy loam	
	25–61	21.9	85.0	10 YR 3/2	mucky loamy sand	
	61–122	17.1	89.3	10 YR 3/2	mucky sand	
DM-200	0–20	53.2		10 YR 3/2	organic	0.2
	20–61	49.3		10 YR 3/2	organic	
	61–122	34.9		10 YR 3/2	organic	0.2
SC-400	0–20	30.1		10 YR 3/1	organic	0.2
	20–61	22.6	19.1	10 YR 3/1	mucky clay	
	61–122	27.7	34.9	10 YR 3/1	mucky clay	0.2

* Adapted from A. F. Clewell et al., 1999.

increase in organic matter. At E3.5–400′ the soil contains 26.6 to 31% organic matter in the upper 0.6 m and 19.3% organic matter from 0.6 m to 1.2 m.

All soils on the Dan May tidal creek transect are organic, containing 34.9% to 55.2% organic matter. The tidal creek soils at Salt Creek have horizons containing high organic matter (22.6% to 30.1%), but most pedons have a high clay content and are mucky sandy clay loam in texture.

Soil bulk density (Table 1) varied with organic matter content. Most of the Histosols had a bulk density of 0.1 to 0.2 g/cm^3. The highest bulk density encountered was 1.0g/cm^3 at E3.5–44′ at a depth of 61 to 122 cm. The texture was a sandy loam with 2.2% organic matter. (Clewell et al., 1999).

Relative elevations are shown in Clewell and co-workers (1999). The transects begin in the River channel at the furthest extent of emergent vegetation. Some of the transects have an elevated berm and some do not. The points where there is an abrupt drop in elevation, such as at W1 between 300′ and 500′, are tidal creeks. These creeks are important because the delta is flooded primarily by the creeks, not by the Suwannee overflowing its banks. Thus, the saltier seawater enters the marsh through these creeks.

The pH of the saturated soils was near neutral with most samples in the 6.4 to 6.8 range over the 18-month period. This included both surface and subsoils. The lowest pH recorded was 5.5 and the highest 7.4. There was no biologically significant seasonal variation.

After moist aerobic incubation for 2 months pH values dropped dramatically, especially in the subsoil. In the 61 to 122 cm horizons (24 to 48 inches), pH ranged from 1.2 to 3.5. In the surface horizon, the pH range was 1.8 to 6.2, but most did not drop more than about 2 units. We attribute this acidification to the oxidation of sulfur-containing compounds to sulfuric acid. Most of the horizons below the surface qualify as sulfidic (pH 4.0 or below). Why some of the surface horizons dropped less than 1 unit while others dropped as much as 4 units raises an interesting question. The redox potential of the surface soils was adequate for sulfate reduction. We know that roots pump O_2 into the root zone, and differences in micro-environment may account for this anomaly.

The redox potential had a range of -12 milli-volts (mv) to -498 mv, but most were in the -200 mv to -400 mv range. This condition is adequate for the reduction of sulfates to sulfur or reduced sulfur compounds. There was no little biologically significant difference in redox potential between surface and subsoil horizons over time.

From observation, plant distribution did not seem to be well related to any parameters described above. We assumed that interstitial soil water salinity in the root zone or surface water salinity would be a controlling factor. Salinity was estimated by electroconductivity (EC). Table 2 shows the range in EC over time and at several distances from the River's mouth and at right angles to the River. It also illustrates the difference in EC in the root zone (5–25 cm) and below. The most saline soils (highest EC) were at W1, which

TABLE 2. Topsoil and subsoil conductivity (mS/cm) by location over time.

Distance from river (meters)	August 1997		November 1997		February 1998		June 1998	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Transect W1								
15	4.9	5.8	11.2	6.7	2.4	8.5	2.6	3.7
30	5.7	13.0	9.9	11.2	—*	—	2.1	6.9
61	5.1	7.0	11.3	7.6	2.2	8.1	2.7	4.7
91	4.9	11.5	13.8	10.9	—	—	3.1	7.4
122	6.9	12.0	14.0	12.1	2.1	11.1	2.8	8.2
152	7.7	12.1	9.4	13.2	—	—	3.5	10.9
Transect W4								
15	2.4	1.9	6.2	3.0	0.2	2.9	1.0	0.7
30	1.9	1.9	5.6	1.6	—	—	1.0	0.8
61	1.4	1.3	4.3	1.9	—	—	0.6	0.6
91	2.3	1.9	4.8	2.9	1.2	3.1	1.0	2.7
122	1.9	3.4	5.8	2.8	—	—	0.8	1.4
152	2.1	4.2	6.0	3.6	—	—	1.1	3.1
Transect W6								
15	0.5	0.5	2.9	1.7	0.1	1.0	0.3	0.3
30	0.8	1.1	3.6	1.2	0.1	1.4	0.3	1.0
61	1.0	2.9	4.4	2.3	0.6	2.1	0.4	1.6
91	2.7	1.1	4.4	2.8	1.2	2.5	0.6	2.3
122	1.4	3.9	3.9	3.2	—	—	0.5	1.1
152	0.9	3.3	4.2	1.4	—	—	—	
Transect E2								
30	—	—	7.6	3.9	—	—	1.4	4.5
61	—	—	4.6	3.3	1.0	2.8	1.2	3.5
91	—	—	4.4	5.4	—	—	1.3	5.5
122	—	—	5.5	5.0	1.7	5.2	1.0	3.6
152	—	—	3.9	2.9	—	—	1.0	2.9
Transect E3.5								
13	—	—	9.2	5.7	2.3	6.5	1.3	5.1
30	—	—	7.8	6.9	—	—	1.4	5.3
61	—	—	5.0	4.8	1.7	4.8	1.3	3.7
91	—	—	2.1	2.5	—	—	0.7	1.6
122	—	—	1.6	1.6	0.6	2.4	0.3	1.3
152	—	—	2.4	1.0	—	—	0.3	0.8
Transect DM								
3	—	—	4.7	3.9	0.7	2.1	0.8	1.1
30	—	—	4.6	2.6	—	—	1.2	1.6
61	—	—	4.1	3.0	1.5	3.2	0.8	2.7
91	—	—	5.0	4.2	—	—	0.8	2.7
122	—	—	5.4	2.9	—	—	0.5	1.4
Transect SC								
5	—	—	9.4	8.7	2.6	5.0	3.1	3.2
30	—	—	9.5	6.9	—	—	3.6	5.9
61	—	—	7.2	8.0	6.8	10.3	4.0	9.5
91	—	—	8.5	8.9	—	—	2.9	6.7
122	—	—	10.4	7.2	2.6	6.9	2.8	5.4
152	—	—	9.9	6.6	—	—	3.3	6.3

* denotes no data collected.

is closest to Gulf waters. These soils are not highly saline when compared with soils not exposed to high amounts of fresh water. Coultas (1997) examined soils on an island just to the north of the mouth of the Suwannee River and found EC of the A1 horizon to be in the range of 19 to 28 milli-Seimens/cm (mS/cm) whereas the highest reading in the delta (W1) was 14 mS/cm. Seawater EC usually exceeds 40 mS/cm.

The EC of the soils at W1 is higher than at other locations because it has the longest exposure to seawater. The subsoil EC at this site is greater than the topsoil (t test significant at 0.01 level), except in November, which is a dry month, and the situation is reversed. The next most saline location was in Salt Creek. This and all other transects reflect the effect of rainfall on EC; i.e. the highest EC occurs during the driest month (Nov.) and the lowest during the wettest month (June). As one goes upriver from W2 to W4 and W6 the EC decreases dramatically due to fresh water flow.

On East Pass, soil water EC was not much different in the lower portion of the River (E2) than in the upper portion (E3.5). At transect E3.5 between 200′ and 300′ there is an abrupt change from needlerush (high EC) to sawgrass (low EC).

Electrical conductivity of interstitial water at Dan May Creek was lower than that encountered at Salt Creek. We suggest this was due to the fact that the Dan May site is farther from the open Gulf waters although fresh water lateral flow from the River can not be discounted.

Vegetation and EC values were not well correlated but some relationships are obvious. *Distichlis spicata* (saltgrass) and *Juncus romerianus* (needlerush) were the predominant plants on the two transects with the highest EC, W1 and Salt Creek. With increasing distance from the Gulf in West Pass, less salt-tolerant plants, such as *Sagittaria lancifolia* become more prevalent. *Sagittaria lancifolia* is more common on the Dan May transect than on the Salt Creek transect, which has a higher EC throughout.

Due to the fact that River flow and rainfall were extremely low in June, 2000, the SRWMD asked A. F. Clewell, Inc. to observe plants in the Delta and perform some limited EC tests (Clewell, 2000). River salinity and EC interstitial soil water was much higher than previously recorded. Soil water extract EC in the root zone at the River berm and at 30m ranged from 17.2% to 141.7% higher than that found in Nov. 1998, with most values 30% to 77% higher. Many plants were stressed (chlorotic, leaf drop, necrotic, wilted) such as ash, *Saggitaria lancifolia,* cattails, and *Scirpus validus.* Sawgrass leaves were killed in the lower reaches of the River. Needlerush, saltgrass, and certain *Scirpus spp.*. showed no signs of stress.

One factor which became obvious early in the study was the effect of storm wrack (layers of dead plant material, such as needlerush) deposited on preexisting vegetation. This often kills preexisting underlying vegetation and allows the invasion or emergence of less competitive species. The low salinity (EC) of most soils facilitates their establishment. Rafts of wrack develop in response to storm tides, flooding of the river and associated winds. Wrack deposition is unpredictable and one raft may cover several hectares of marsh.

In another effort to find a vegetation indicator, we extracted interstitial water from the river bank soils at the point where emergent vegetation extended furthest into the river. Electrical conductivity (mS/cm) ranged from 4.0 at W1 to 0.3 at W6 and 1.3 at E2 to 3.6 at E3.5. EC correlated weakly or not at all with individual plant species (Clewell et al., 1999). A strong correlation was calculated between maximum EC in River waters and the ratio in abundance between sawgrass and needlerush on the adjacent riverbank. This ratio indicates a point on the riverbank that moves up or downstream as salinity fluctuates (Clewell et al., 1999).

Because of the large amount of data collected, only data on selected pedons are reported. The complete data set is in Clewell and co-workers (1999), and is available from the Suwannee River Water Management District (9225 CR 49, Live Oak, FL, 32060).

CONCLUSIONS—Mineral soils with high organic matter (15%–30%) are common in the Suwannee River delta and are very difficult to separate from organic soils in the field. This poses a problem for field mapping. Large amounts of C are sequestered in the delta.

Soil water EC in the marsh soils of the Suwannee delta decreases with distance from the Gulf. There is some influence of soil water EC on plant distribution but EC is not a major factor. Electrical conductivity is highest in November, the driest month and lowest during periods of highest rainfall.

All soils are highly anoxic. Most soils are Sulfaquents, but many are Sulfisaprists.

The relatively random plant distribution is partially due to wrack smothering existing vegetation followed by invasion by opportunistic species. The low salt content of the soil permits a wide variety of plants to compete.

We found that the best measure of salt-water intrusion is the ratio of sawgrass and needlerush on the riverbank and maximum river water salinity.

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MAPPING EVERGLADES ALLIGATOR HOLES USING COLOR INFRARED AERIAL PHOTOGRAPHS

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Abstract—*Color infrared (CIR) aerial photographs were used to map alligator holes in a 2,442 km² area (Water Conservation Area 3) of the Everglades. Open-water ponds appeared as clearly defined black spots on the photographs. Three types of alligator holes were identified based on differing CIR signatures: Type 1 holes were encircled by a bright red ring indicating a surrounding zone of woody vegetation (small trees and shrubs); Type 2 holes were not surrounded by a change in pixel brightness or tone, indicating a round open water pond within the existing vegetation matrix without a surrounding ring of woody vegetation; and Type 3 holes were immediately adjacent to elongated red ovals (small tree islands) formed from the construction of spoil banks and are termed "artificial holes." Eight hundred forty-five alligator holes greater than 5 m in diameter were mapped, including 309 Type 1, 331 Type 2, and 205 Type 3 holes. These alligator holes ranged from five to 15 m in diameter and 20 to 150 cm deeper than the surrounding marsh (n = 49). Based on the ground-truthing of 89 mapped alligator holes, 88 percent were successfully located in the field, 83 percent were correctly characterized, and the holes were found within 60 m, on average, of their map coordinates.*

American alligators (*Alligator mississippiensis*) in the Florida Everglades have the ability to alter the structure of the landscape (Craighead, 1968; Kushlan, 1974). Due to an alligator's large size and weight, and the soft, organic, peat sediments of central Everglades marshes, alligators maintain, and sometimes create, small ponds called alligator holes by wallowing into the peat, thereby mounding soil and vegetation around the perimeter. This causes significant topographic and hydrologic variation in an otherwise flat, shallow wetland landscape, resulting in increased vegetative and wildlife diversity (Craighead, 1971).

Alligator holes are approximately 1 m deeper than the surrounding marsh, reaching down to the limestone bedrock. They may range from 2 to 15 m in diameter and are found in a variety of major wetland habitats including sawgrass marsh (*Cladium jamaicense*), wet prairie (emergent rush marsh including *Eleocharis* spp. and *Rhynchospora* spp.), and slough [deeper water with floating aquatic plants such as spatterdock (*Nuphar luteum*), white water lily (*Nymphaea odorata*), floating heart (*Nymphoides aquatica*), and bladderwort (*Utricularia* spp.)]. Trees and shrubs, such as willow (*Salix caroliniana),* often take root on the raised banks surrounding alligator holes. In other cases, alligator holes may simply be small open water depressions hidden within the surrounding vegetative matrix. Once established, alligator holes are kept free from encroaching vegetation by the important maintenance activities of the resident alligator.

Alligator holes have long been hypothesized to provide critical dry season refugia for Everglades wildlife (Davis, 1943; Kushlan, 1974). As the surrounding marsh dries down, fish and other aquatic organisms concentrate in the alligator hole, becoming an important food source for nesting wading birds, and resident alligators. When water levels increase, surviving organisms reproduce and colonize surrounding wetlands. For this reason, alligator holes have been recognized as important components in the process of life and death within the Everglades ecosystem (Mazzotti and Brandt, 1994).

Although the importance of alligator holes in the Everglades is widely recognized, only one alligator hole has ever been quantitatively studied (Kushlan, 1972; 1974), and no inventory or mapping effort has been made. As a result, the significance of alligator holes to the overall structure and function of the Everglades is not known. The objective of this study was to find a simple procedure to identify, classify, and map alligator holes using CIR aerial photographs. To accomplish this, we asked several questions. Could alligator holes be identified from CIR aerial photographs? What size holes could be identified? How many types of alligator holes could be described? How accurate was the identification and location of alligator holes? Could this method be applied effectively over a large area?

MATERIALS AND METHODS—*Study Area*—This study focused on Water Conservation Area 3 (WCA 3), a 2,442 km^2 water impoundment that extends from the L-5 levee (Palm Beach County, Florida) in the north to U.S. 41 (Dade County, Florida) in the south (Figure 1). The major habitats of this shallow, peat wetland are sawgrass marsh, wet prairie, and freshwater slough, which are dotted with occasional tree islands (clumps of small trees and shrubs) (Jordan et al., 1997). Encompassing approximately one-third of the remaining Everglades fresh water marsh, the major functions of WCA 3 are water supply, flood control, public recreation, and wildlife habitat.

Data Sources—Alligator holes were mapped using color infrared (CIR) aerial photographs because they provided the necessary detail, were readily available, and covered the full extent of the study area. In addition, CIR photographs are superior to conventional color or black and white photographs for distinguishing between water and vegetation, which was critical for this study, (Schneider, 1966; Shima and Anderson, 1976; Howland, 1980). The CIR photographs, flown in September 1994, were obtained from the South Florida Water Management District (SFWMD). Accompanying the photographs were a set of ground control points (GCP's) that were collected by the SFWMD using a differentially corrected Global Positioning System (DGPS) and helicopter. Approximately four control points per photograph were flown and recorded as an image pinprick and as line-work on mylar overlays. Individual photographs were 9-by 9-inches at a scale of 1:24,000, resulting in a 3,025 ha photograph (5.5 km per side). A total of 180 photos were used to map WCA 3.

Pilot study—A pilot study was conducted within WCA 3 on a 250 km^2 area to determine if alligator holes could be successfully identified from the CIR aerial photographs. Fourteen photos were professionally scanned at one-meter ground resolution (40 μm) and stored on CD-ROM. The resulting digital color infrared (DCIR) raster images were approximately 100 Mb each. The DCIR images were imported into EASI/PACE (PCI Geomatics, Ontario, Canada)

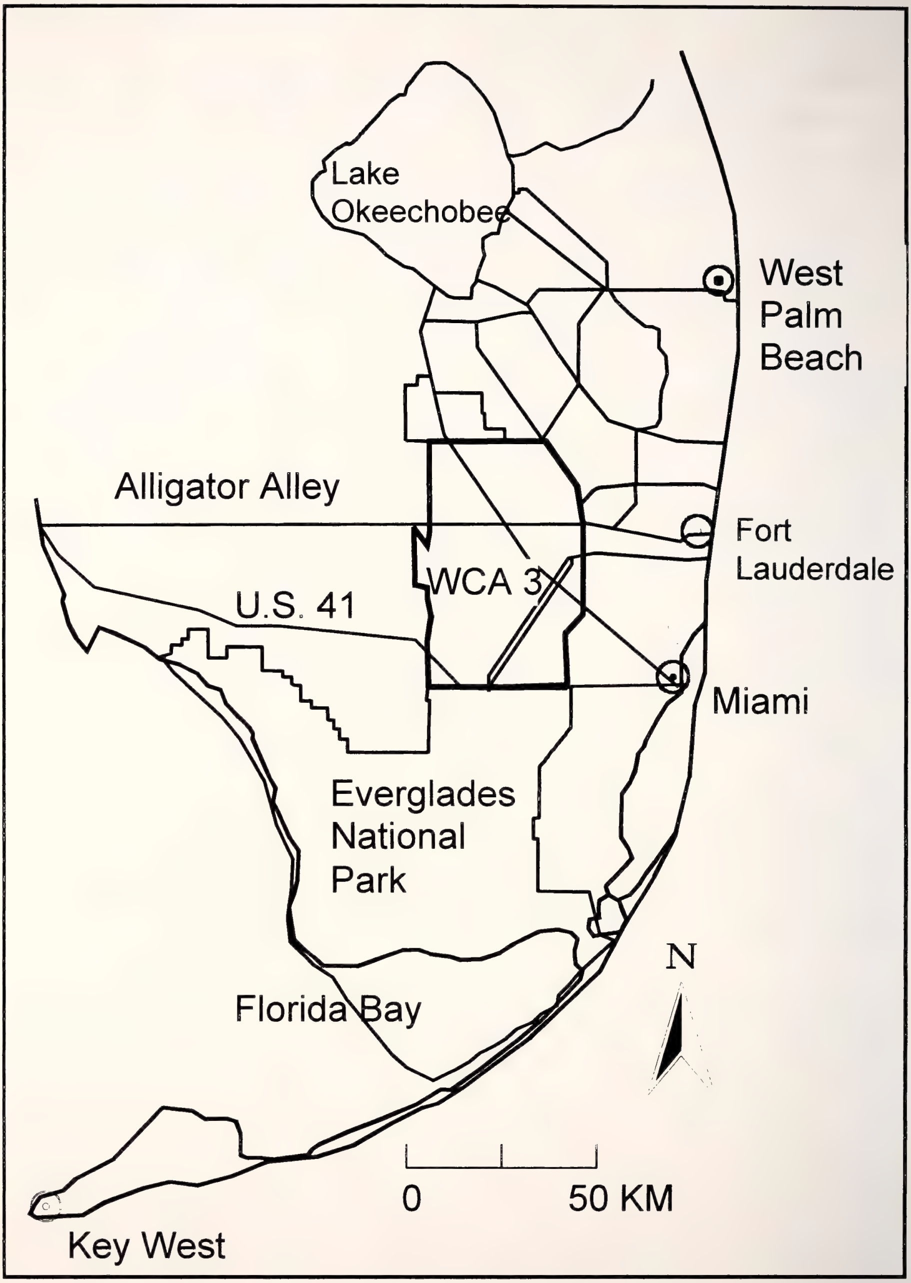

FIG. 1. Location of Water Conservation Area 3 in southern Florida.

image processing software and georeferenced in the Universal Transverse Mercator (UTM) ground coordinate system (Zone 17) tied to the North American Datum of 1983 (NAD 83) using the GCP's supplied by the SFWMD.

Potential alligator holes were identified on the positive CIR film as small, dark, open-water areas and subsequently located on the DCIR images on the computer. A light table and magnifying loupe assisted in the identification of alligator holes from the CIR photos in positive transparency format. Color inkjet printouts of digital alligator hole enlargements were used to record field characteristics associated with the holes such as open water, sawgrass, woody vegetation, and shadows. The printouts contained a UTM grid for navigation to a specific alligator hole with a DGPS and airboat or all-terrain vehicle. This information assisted in classifying alligator holes into different types, and determining the minimum pond size that can be interpreted from the photographs.

Mapping WCA 3—After the pilot study demonstrated the potential of CIR photography for mapping alligator holes, a manual interpretation (U. S. Fish & Wildlife Service, 1994) of all air photos covering WCA 3 was then conducted. With the aid of a light table and magnifying loupe, potential alligator holes were located on each of the original 1:24,000 scale diapositives and plotted on 9-by 9-inch clear acetate overlays with a fine point permanent marker (0.4 mm nib). In addition, the location of the four GCP's, airboat trails, and canals were plotted on the overlay for each photo.

To increase the amount of ground control per overlay (four GCP's are minimal), while reducing the number of overlays for computer processing, 20 adjacent overlays were assembled into a mosaic by lining up common control points, airboat trails, canals, and alligator holes. A second, continuous, transparent overlay then was placed over the mosaic, and all alligator holes, airboat trails, canals, and the 20 control points were retraced onto a final single sheet. The large overlays were photographically reduced to 8½-by 11-inch paper maps to accommodate the page size of the scanner. Each reduced line drawing was scanned as a sharp black and white drawing at 75 dpi creating a digital raster image. Once scanned, the digital line drawings were imported into EASI/PACE image processing software and georeferenced using the ground control coordinates collected by the SFWMD. Coordinates were entered from the keyboard and assigned to their respective tick marks recorded on the digital line drawings. The image was georeferenced using a second order polynomial solution and a nearest-neighbor resampling algorithm.

The georeferenced images then were imported into SPANS geographic information system (GIS) version 6.0, and compared to an existing georeferenced canal vector layer (obtained from the SFWMD) to verify the success of georeferencing. To obtain a vector GIS layer of alligator holes that allowed the association of attribute information to individual alligator holes, a manual vectorization process was performed by on-screen digitizing a point layer of alligator holes (in addition to the study area boundary and major airboat trails). Field data collected during groundtruthing were linked to each alligator hole within the GIS database for subsequent analysis.

A random subset of a minimum of ten percent of potential alligator holes was ground truthed to evaluate the error of commission. Aerial photographs were randomly chosen, and all potential holes within that area were visited to maximize efficiency. Potential holes were navigated to using a DGPS and airboat. An alligator hole was determined to exist at the mapped location if three criteria were met. First, if a depression in the muck or limestone relative to the surrounding marsh was found. Second, if the depression had a definite round or oval boundary as indicated by the change in vegetation. Third, if the interior of the alligator hole had no emergent vegetation. Field information collected at the randomly selected alligator holes included pond length, width, and center depth, marsh water depth 10 meters from the edge of pond, field UTM coordinates, surrounding zonation of vegetation, and photographs.

Due to a lack of the ability to do aerial surveys the error of omission was not evaluated.

RESULTS—*Pilot study*—The identification of alligator holes was easier and more efficient using the positive CIR film, light table, and magnifying loupe than the DCIR images. The positive film under magnification revealed more detail than the 1-m DCIR images, and it was more efficient to manipulate the photos on the light table than to pan and zoom digital images in the computer. Within the 250-km^2 pilot study area, a total of 548 potential holes were identified from 14 CIR photographs. Twenty-three potential alligator holes were ground-truthed using the digital inkjet enlargements. The alligator holes were located by DGPS to within fifty meters of the computer-generated locations (varying from 0 to 26 m in the x direction and 0 to 50 m in the y direction). The root-mean square error (RMSE) was 15.1 m.

Investigation of the image spectral characteristics showed that open water appeared black, sawgrass was pink with mottled or rough texture, woody vegetation was dark pink to red with a rough texture, and cattail (*Typha domingensis*) was mixed, appearing as white, light pink, or red, depending on density, water depth, and other associated plants. The spectral signatures for open water and woody vegetation were consistent across the 23 printouts and could be readily identified. Five of the DCIR printouts with small islands of woody vegetation contained neither a clear round black spot on the image nor an open water pond in the field and were determined not to be alligator holes. These small islands of woody vegetation were specifically investigated to determine if alligator holes were present in areas where the CIR photographs did not reveal well-defined circular black spots indicating ponded water.

Information on the 1-m resolution DCIR printouts was compared to actual field values. There was no significant difference between the DCIR pond diameters and actual pond diameters (paired t-test, df = 21, P = 0.69), thereby validating the accuracy of the information obtained from photographs. The minimum pond size identified on the photographs was five meters in diameter. Nine unmapped alligator ponds, less than five meters across, were located in the field in close proximity (within 20 m) to larger ponds previously identified on the photographs.

Alligator holes were classified into three types based on different spectral characteristics on the CIR photos that resulted from varying physical and vegetative structure. Type 1 alligator holes were round open water ponds surrounded by either shrubs and trees, a ring of cattails, or a combination of both. They are identified on the photos as distinct black spots surrounded by an immediate red ring (darker in hue than the surrounding vegetation). Type 2 alligator holes were round open water ponds having a distinct boundary clearly offset from the surrounding vegetation matrix that are not surrounded by shrubs or trees. They were identified on the photos as distinct black spots within a red or pink matrix of marsh vegetation of varying intensity, and are not surrounded by a bright red ring. Type 3 alligator holes were termed “artificial” since they were formed from the construction of spoil banks, approximately 40 meters long by 15 meters wide, by digging up the muck with a drag line and piling it adjacent to the hole. A few hundred of these artificial islands were created in the 1970s for the benefit of wildlife (specifically deer) in times of extremely high water, and are found in close proximity (within 500 m) to each other as they string out from the levees. On the photos, Type 3 artificial holes were identified as round or elongated black spots of open water immediately adjacent to elongated islands of bright red woody vegetation. Only artificial islands that appeared to have an adjacent pond were mapped.

Mapping WCA 3—A total of 845 alligator holes were identified throughout WCA 3 from the 180 CIR aerial photographs. This includes 309 Type 1 holes with surrounding shrubs or trees, 331 Type 2 open-water ponds without a discernable ring of surrounding shrubs, and 205 Type 3 alligator holes at artificial islands (Figure 2).

A total of nine overlay-mosaics were created (20 overlays per mosaic) that covered the full extent of WCA 3. After the mosaics were reduced, scanned, and georeferenced, the resultant RMSE averaged four pixels for a thirty-meter resolution image (or 120 m on the ground). The canals on the georeferenced images were approximately within two pixels (sixty meters) of an existing georeferenced canal file (obtained from SFWMD), verifying both the georeferencing and the accuracy of plotting information on the acetate. This comparison of data sets indicated that the data manipulation (plotting information on acetate, recopying, reducing, and scanning) did not compromise its spatial integrity beyond the purposes of this study. In large part this is due to the very low topographic relief experience across WCA 3, resulting in minimal photogrammetric displacement of ground elements, but also important are care and precision when manually manipulating data.

A subset of the alligator holes was located in the field to assess the commission error of the alligator hole map. Out of a total of 89 mapped alligator holes that were searched for, 11 holes could not be located, resulting in an 88 percent commission rate for the map. For the individual alligator hole types, 90 percent (n = 42) of Type 1 was located, 74 percent (n = 27) of Type 2 was located, and 100 percent (n = 20) of Type 3 holes searched for was found. In addition, the commission error was not spatially independent. The majority of mis-commissioned holes (8 of 11 or 73 percent) were located in the southwest portion of the study area, a deep-water, open-slough region. The marsh water depth for the southwestern area (74 cm ± 16, n = 16) was significantly deeper (*t*-test, $P \leq 0.001$) than the central region of WCA 3 (40 cm ± 11, n = 10). No structures indicating an alligator hole were located for these eight potential holes, where it is likely that open water patches within the slough habitat were misidentified. The remaining three misidentifications, located in a northwestern sparse sawgrass marsh averaging 42 cm ± 12 water depth, were caused by round open water patches, averaging nine meters in diameter, but without depressions in the muck.

The accuracy of the identification of alligator holes was assessed by comparing the alligator hole classifications from the photographs to the vegetation zonation in the field (Table 1). Overall, 83 percent of the alligator

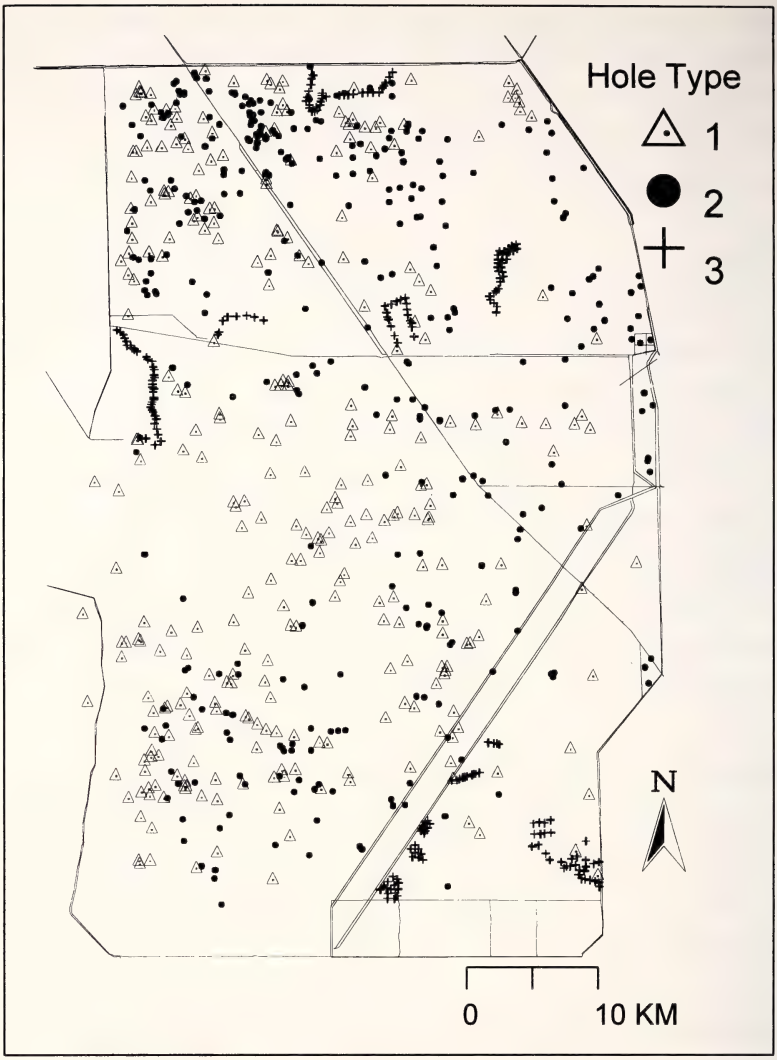

FIG. 2. Map of Everglades alligator holes. Type 1 holes were surrounded by small trees or shrubs, type 2 holes were in the marsh, and type 3 holes were associated with artificial tree islands.

holes investigated had physical characteristics that conformed to their identified types. Of the 38 Type 1 holes located in the field, 74 percent (28 holes) were correctly classified with surrounding trees and/or cattails, while low shrubs and sawgrass surrounded the remaining 26 percent (10 holes). Of the 20 Type 2 holes located, 85 percent (17 holes) were found in sawgrass, while 15 percent (3) were surrounded by a cattail stand and therefore misclassified. No Type 2 holes investigated were surrounded by trees. Fi-

TABLE 1. Classification error matrix to assess the accuracy of map types.

	Computer Classification (Column Total)			
Field Classification	Type 1	Type 2	Type 3	Row Total
Type 1	20	0	0	20
Type 1 (cattail)	8	3	0	11
Type 2	10	17	0	27
Type 3	0	0	20	20
Column Total	38	20	20	78
Classification Accuracy	28/38	17/20	20/20	65/78
	74%	85%	100%	83%

nally, all Type 3 holes investigated (20 holes) were located adjacent to artificial tree-islands, and were therefore correctly classified.

The spatial accuracy of the alligator hole locations was estimated, not only by the RMSE generated through the georeferencing process, but more importantly by comparing actual alligator hole ground locations to the computer generated estimate. The difference between the computer coordinates and those collected by DGPS in the field are plotted in Figure 3. The average error between coordinate pairs was 60 meters, distributed evenly in all directions. Therefore, the approximate spatial accuracy of the mapped gator hole coordinates is ±60 m.

Alligator holes ranged from five meters to over 15 m in diameter and 20 cm to 150 cm in basin depth (86 cm mean depth). A comparison of the surface area of open water shows Type 2 holes to be smaller (43 ± 33 sq m, n = 21) than Type 1 (74 ± 33 sq m, n = 28), (*t*-test, $P = 0.002$) (Figure 4). Large holes are generally deep, reaching the limestone substrate in approximately one meter, while small holes exhibit more variability. Most small, deep holes were located in cattail stands.

DISCUSSION—Color infrared aerial photographs (1:24,000) were a useful and efficient data source for mapping alligator holes over a large area. The methods described here can be used to map other areas of the Everglades. A total of 640 natural plus 205 artificial holes were identified using 180 photos over a 2,442 km^2 area. Three types of alligator holes were identified in this central Everglades area. In general, alligator holes with surrounding shrubs and trees (Type 1) tend to be larger and deeper than alligator holes without surrounding shrubs or trees (Type 2). Alligator ponds surrounded by cattail were classified as either Type 1 or Type 2, and it would be useful in the future to distinguish cattail zonation on the photographs. The third type of alligator hole (Type 3) is identified from its association with elongated, man-made, tree islands, and varies in size and shape from a few meters in diameter to over 40 meters in length (the size of the spoil bank).

It is likely that in other areas of the Everglades with more tree islands (Arthur R. Marshall Loxahatchee National Wildlife Refuge, Shark Slough

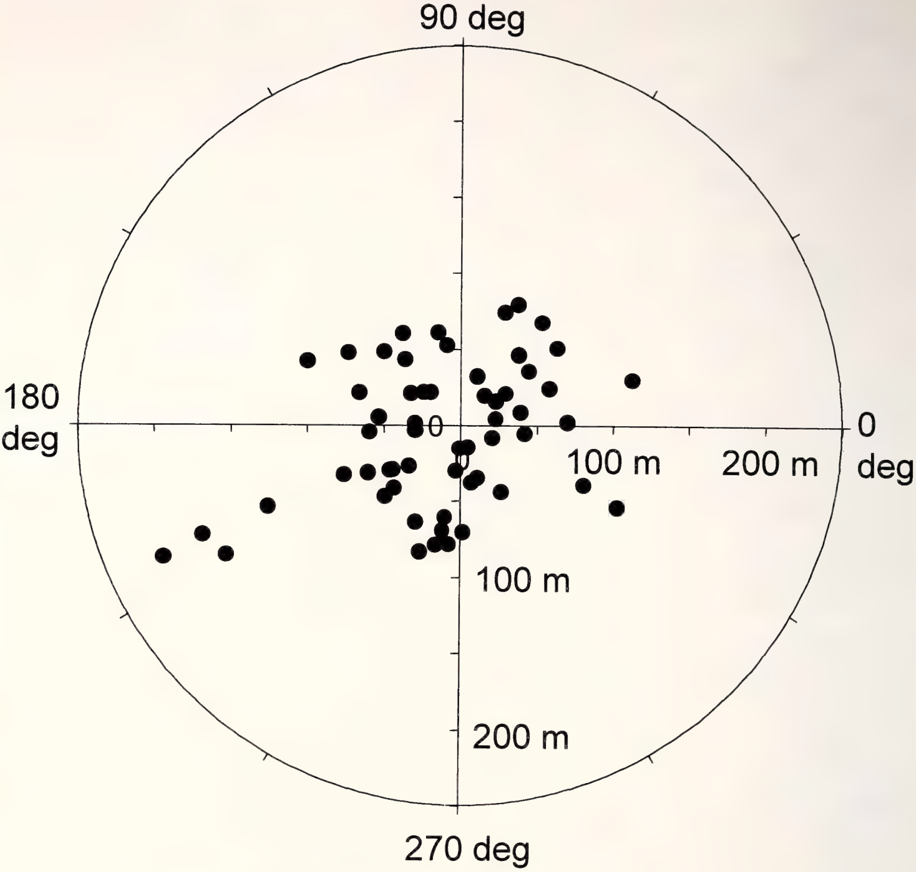

FIG. 3. Polar plot of the distance (meters) and bearing (degrees) errors for the computer generated alligator hole coordinates (UTM) as compared to actual field locations found during ground truthing. Average error is 60 meters.

in Everglades National Park) or a different substrate (rocky glades, Everglades National Park) there will be other types of alligator holes.

The error of commission for alligator holes depended on size, surrounding vegetation, and habitat (matrix vegetation). The majority of commission error was located in deep water, open slough habitat where breaks in the floating surface vegetation resulted in round open-water patches. In addition, round, vegetation-free patches were misidentified in shallow areas. These open patches may be caused from spot fires. The overall error of omission for the map was not determined, but alligator holes less than 5 m across were present though they were not mapped. While it is possible that larger alligator holes were also omitted it is likely that the majority of omission lies below the five-meter minimum-mapping threshold. A combination of aerial and ground surveys could be employed to investigate this error in detail. Because of the patchy, heterogeneous makeup of the marsh vegeta-

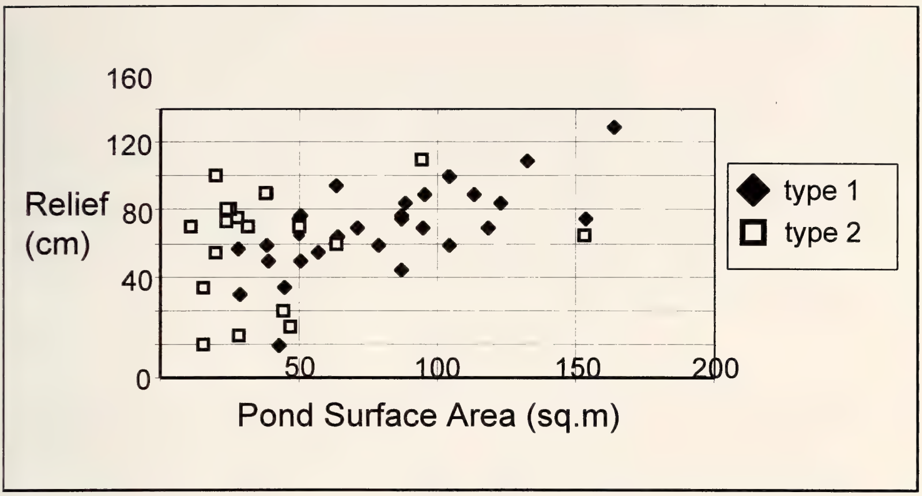

FIG. 4. Scatter plot of size vs. topographic relief (center pond water depth minus surrounding marsh water depth) for both Type 1 and Type 2 alligator holes.

tion, identification of entities this small would rapidly increase the error of commission. Small alligator holes with a distinct boundary were difficult to distinguish from small, irregular open-water patches within slough habitat that did not have a distinct vegetative boundary. Numerous potential alligator holes were identified during the pilot study in two areas of the marsh (approximately 25 km^2 each) where the sawgrass becomes patchy and merges into slough habitat. Investigation of these sites proved that caution should be applied when identifying small, round, open-water ponds as alligator holes in areas of patchy sawgrass and slough communities. After these sites were re-evaluated, the number of potential alligator holes within the pilot study area dropped from 548 to 173 holes.

The positional accuracy of the mapped gator hole locations was determined to be ± 60 m, based on comparison with field data. This positional accuracy could have been improved if the line work was scanned at a higher resolution, resulting in a smaller pixel size and if the overlay did not have to be reduced to 8.5 by 11 inches to fit the scanner. Nevertheless, the methods employed were sufficient for locating alligator holes in the field, and acceptable for compiling a relatively small-scale map of alligator hole point locations. The positional accuracy may not be sufficient for spatial analysis.

This mapping effort was accomplished with desktop computing systems, using PC image processing and GIS software. Management agencies will increasingly recognize the value of spatially analyzing environmental data. This study demonstrates an efficient, economical method for high resolution mapping over large spatial extent, and the value of integrating remote sensing and field biology in a GIS/GPS environment.

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Environmental Chemistry

BACKGROUND CHARACTERISTICS OF SOILS OF KENNEDY SPACE CENTER, MERRITT ISLAND, FLORIDA: SELECTED ELEMENTS AND PHYSICAL PROPERTIES

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ABSTRACT: *We determined background total concentrations of selected elements, bulk density, cation exchange capacity (CEC), pH, and texture for surface soils of Kennedy Space Center (KSC), Merritt Island, a complex barrier island. We classified soils into 10 classes: coastal, acid scrub, coquina scrub, flatwoods, hammocks, freshwater wetlands, saltwater wetlands, citrus scrub, citrus hammock, and disturbed. Within each class, 20 sites were sampled, and the samples analyzed by standard techniques. Four elements (Sb, Be, Co, Ni) were always below detection. Barium, Cd, Se, Ag, and Tl were seldom detected. Arsenic, Cu, and Hg were above detection limits with intermediate frequency, while the other metals were frequently detected. Elements, above detection in >25% of samples, (Al, As, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, K, Na, V, and Zn) varied significantly among soil classes, as did bulk density, pH, and CEC (ANOVA, $p<0.001$). Chromium, Cu, Mn, and Zn concentrations were high in agricultural soils, due to sources in fertilizers or pesticides. Variation in other elements was related to soil origin, age, and degree of leaching. Bulk density was lower but CEC higher in soils where organic matter had accumulated. Mean grain size varied among soil classes; most were fine sands, but coastal and coquina scrub soils were medium sands due to the presence of shell fragments. These data indicate that contamination of KSC soils has not been widespread.*

JOHN F. KENNEDY Space Center (KSC) has been the primary launch complex for the United States Space Program since the 1960s. Various hazardous materials have been used in the operation of this launch complex leading to contamination concerns. Investigation and in some cases remediation of sites that may have been contaminated is required under the Resource Conservation and Recovery Act (RCRA). Investigation of such sites requires comparing chemical parameters of the site to screening values. State or regional screening values may not represent background values of a local environment. In this study, we developed background values for chemical composition of soils specific to KSC.

The U.S. Fish and Wildlife Services manages much of KSC as Merritt Island National Wildlife Refuge. Some is included in Canaveral National Seashore, managed by the National Park Service. These lands and waters support numerous threatened and endangered species and are critical to maintaining regional biodiversity (Schmalzer and Hinkle, 1990; Breininger et al., 1994; 1998). Contamination in this environment could pose ecological risk as well as regulatory issues.

KSC is a complex environment; the chemical composition of its soils is a product of geologic history, climate, interactions with biota, and anthropogenic effects. KSC is located on the east coast of central Florida in Brevard County, at approximately 28.5 degrees north latitude and 81.7 degrees west longitude on Merritt Island, a relict barrier island (Fig. 1); it incorporates about 57,000 ha of land and lagoons. Cape Canaveral Air Force Station (CCAFS) occupies the adjacent Cape Canaveral barrier island. Large water bodies surround these lands: the Atlantic Ocean, Banana River, Indian River, and Mosquito Lagoon.

The climate is warm and humid with mean annual precipitation of 136.6 cm (Mailander, 1990). The wet season extends from May to October, and the rest of the year is relatively dry.

Florida has a complex geologic history (Randazzo, 1997; Scott, 1997). To simplify, the geology beneath KSC consists of a limestone plateau of Eocene age overlain by Miocene clays, phosphatic limestone, and phosphorite, and unconsolidated beds of fine sand, shells, and clay of late Miocene or Pliocene age. Surface strata are primarily unconsolidated white to brown quartz sand containing beds of sandy coquina of Pleistocene and Holocene age (Cooke, 1945; Brown et al., 1962).

The alternating high and low sea stands of the Pleistocene and Holocene shaped the surface of KSC and Brevard County. The outer barrier island and Cape Canaveral formed after sea levels rose when the Wisconsinan glaciers retreated (Davis, 1997). It is considered Holocene in age, with its formation beginning about 7,000 years ago (Brooks, 1972; 1981). Cape Canaveral is part of a prograding barrier island complex (White, 1958; 1970) with alternating periods of deposition and erosion (Chaki, 1974).

Merritt Island also formed as a prograding barrier island complex, earlier than Cape Canaveral (White, 1958; 1970). Multiple dune ridges apparently represent successive stages in this growth. The western portion of Merritt Island is substantially older than the east (Brooks, 1972; Clapp, 1987).

The soil pattern of KSC is complex (Huckle et al., 1974; Baldwin et

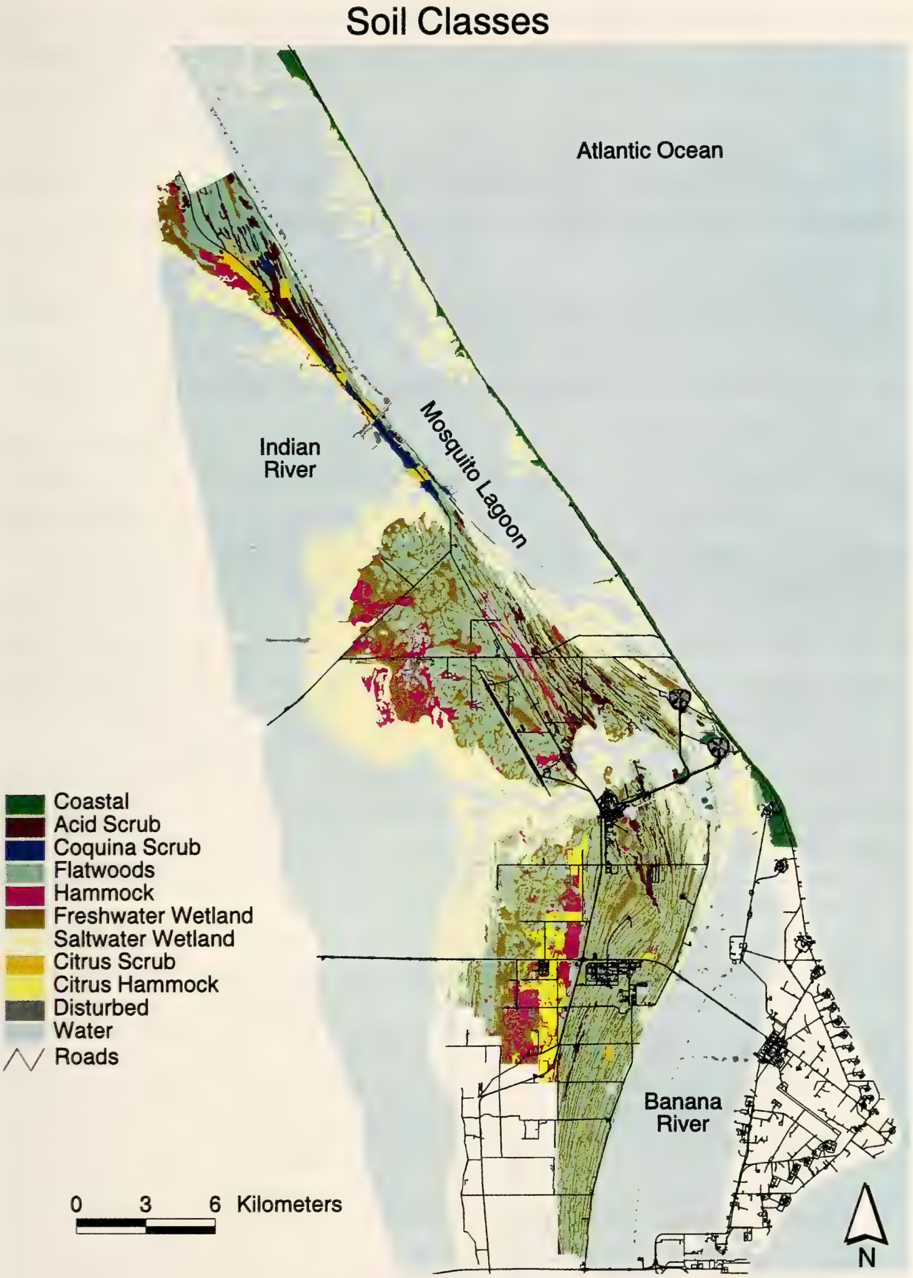


FIG. 1. Distribution of soil classes on Kennedy Space Center.

al., 1980) with 58 soil series and land types represented. Topography has a dramatic effect on soil formation here. Relatively small elevation changes cause substantial differences in the position of the water table that, in turn, affect leaching, accumulation of organic matter, and formation of soil horizons. In addition, proximity to the lagoon systems influences soil salinity.

The primary sources of parent material for KSC soils are sands of mixed terrestrial and biogenic origin. The terrestrial material originated from southern rivers carrying sediments eroded from highly weathered Coastal Plain and Piedmont soils; these sediments are quartzose with low feldspar content (Milliman, 1972). The biogenic carbonate fraction of the sand is primarily of mollusk or barnacle origin (Milliman, 1972). Some differences in soil parent material do occur, particularly that between soils formed in deposits over limestone or coquina compared to those formed in sand.

Soils on Cape Canaveral, False Cape, and the barrier island on the east side of Mosquito Lagoon are younger and less weathered than those of Merritt Island. Well-drained soils in these areas retain shell fragments in the upper layers, while those inland on Merritt Island do not. The presence of shell fragments influences soil nutrient levels, particularly calcium and magnesium, and pH. The eastern and western sections of Merritt Island differ in age with the eastern section of Merritt Island retaining marked ridge-swale topography from its formation as a barrier island (Brown et al., 1962).

Humans have occupied central Florida for thousands of years and interacted with the environment (Davison and Bratton, 1986; Bense, 1994). Activities that would affect background chemical composition of soil are relatively recent. Euro-American settlement in the 19th and early 20th centuries resulted in logging, citrus agriculture, and free-range grazing of cattle (Davison and Bratton, 1986). Use of chemical fertilizers and pesticides developed over time in agriculture, particularly citrus.

METHODS—*Soil classification and site selection*—Adequate sampling of all 58 series or land types was impossible. Therefore, it was necessary to group soil series into similar classes before sampling. We divided soils into ten classes (Table 1) that reflected important differences. We selected twenty sample locations in each for a total of 200 locations. Sample number per group was determined based on variation in soil chemistry found in previous studies (Schmalzer and Hinkle, 1992a; 1992b). Sample sites were located away from areas known or suspected to be contaminated. Twenty additional samples were collected for quality control purposes. Additional information is given in Schmalzer and co-workers (2000).

Sampling—A 0–30 cm layer composite sample was collected at each location with a stainless steel scoop and bowl. Samples for bulk density were collected using a stainless steel ring, which was hammered into the ground. Standard sampling and decontamination procedures were followed (NASA, 1996). Environmental Conservation Laboratories (ENCO) was subcontracted for sample collection and analysis.

Chemical analysis—Total concentrations of selected elements were analyzed using inductively coupled plasma-atomic emission spectrometry, atomic absorption-direct aspiration flame absorption, atomic absorption-furnace absorption, or cold-vapor-atomic absorption (Table 2, USEPA, 1983; 1996).

TABLE 1. Soil classification for Kennedy Space Center. Soils are grouped into ten classes based on similarities.

Division	Subdivision	Class
Upland	Well-drained	Recent, coastal, alkaline soils—vegetation is coastal dunes, coastal strand, or coastal scrub COASTAL CLASS
		Old, inland, acid soils—vegetation is scrub or scrubby flatwoods ACID SCRUB CLASS
		Inland, circumneutral soils over coquina—vegetation is scrub or xeric hammock COQUINA SCRUB CLASS
	Poorly-drained	Acid, sandy soils—vegetation is flatwoods FLATWOODS CLASS
		Circumneutral to alkaline soils over coquina or limestone—vegetation is hammock HAMMOCKS CLASS
Wetland	Freshwater	Inland, freshwater soils—vegetation is freshwater marshes or hardwood swamps FRESHWATER WETLANDS CLASS
	Saline	Coastal, brackish to saline soils—vegetation is saltmarsh or mangroves SALTWATER WETLANDS CLASS
Agricultural	Scrub soil	Active or abandoned citrus on acid or coquina scrub soils CITRUS SCRUB CLASS
	Hammock soil	Active or abandoned citrus on hammock soils CITRUS HAMMOCK CLASS
Disturbed		Soils modified by construction or filling DISTURBED CLASS

Soil samples were also analyzed for cation exchange capacity (CEC) (USEPA, 1996). Soil pH was determined on a 1:1 soil/water slurry by electrode (USEPA, 1996). Bulk density was determined by the core method (Blake, 1965). Soil texture was determined by sieving through a series of standard sieves (Day, 1965; McLane, 1995).

Data analysis—Data analysis was conducted using SPSS Version 9 (SPSS Inc., 1999). We determined the frequency of parameters occurring above the detection limits and used box plots to scan for obvious outliers. Normality of distributions was tested using normality plots and Kolmogorov-Smirnov statistics with Lilliefors significance levels. We tested whether parameters differed among soil classes with the Kruskal-Wallis nonparametric analog of one-way analysis of variance. Discriminant analysis was used to test whether soil classes differed based on a set of parameters frequently above detection. Where the sample size of data above detection was sufficient, we used one-way analysis of variance (ANOVA) of transformed data ($\log_{10}$) followed by Games-Howell post hoc tests to determine how parameters differed among soil classes. Games-Howell tests do not assume equal variances (Ray and Quinn, 1989). Patterns of correlations among transformed parameters were examined with principal components analysis (PCA) (PC-ORD, McCune and Mefford, 1999).

The occurrence of data below detection levels is a complication for data analysis and interpretation. Various approaches can be taken (e.g., Breckenridge and Crockett, 1995); here one-half the detection level was substituted for values below detection (USEPA, 1998).

TABLE 2. Parameters, EPA methods used, and detection limits in soil samples.

Parameter	EPA method	Lab reporting limit, mg/kg
Aluminum	200.7	20
Antimony	204.2	2
Arsenic	6010	0.5
Barium	6010	20
Beryllium	6010	1
Cadmium	6010	1
Calcium	6010	25
Chromium	6010	1
Cobalt	6010	5
Copper	6010/7210	5
Iron	6010	10
Lead	6010	1
Magnesium	6010	25
Manganese	6010	1
Mercury	7471	0.01
Nickel	6010/7520	5
Potassium	6010/7610	25
Selenium	6010	2
Silver	6010	2
Sodium	7770	25
Thallium	6010	1
Vanadium	6010	1
Zinc	6010/7950	5
pH	9045	NA
Cation Exchange Capacity	9081	NA
Bulk Density	Core Method	NA
Texture (No. 4, 10, 40, 60, 100, 200)	Sieve Method	NA

The graphic mean grain size of each soil type was calculated according to the method defined by Folk and Ward (1957). This method involves the use of grain size frequency data obtained from sieve analysis. Grain size in mm was converted to phi units (ϕ) (Eqn. 1)

$$\phi = -\log_2 \text{mm}. \tag{1}$$

The cumulative percentage of grain size was plotted on a probability y-axis and phi size was plotted against the x-axis. The phi size of the 16, 50, and 84 percentage was marked, and we used the equation provided by Folk and Ward (1957), (Eqn. 2).

$$\frac{16\phi + 50\phi + 84\phi}{3} = \text{mean grain size in } \phi. \tag{2}$$

Phi size was then converted to millimeters and assigned to the appropriate size class in the Wentworth (1922) ratio scale preferred by most sedimentologists.

RESULTS—*Soil classification and distribution*—The soil classification used grouped soil series and land types with similar taxonomic status (Soil Survey Staff, 1975) (Table 3). Soil classes were distributed across the landscape in patterns related to topography, geology, landscape age, and human influences (Fig. 1). Flatwoods, saltwater wetlands, and freshwater wetlands were the largest soil classes (Table 4).

Soil chemical and physical parameters—Four elements (Sb, Be, Co, Ni) were below detection in all samples. Barium, Cd, Se, Ag, and Tl occurred in few samples above detection limits (Table 5). Arsenic, Cu, and Hg were above detection limits with intermediate frequency, while the other elements were frequently above detection limits (Table 5).

There was considerable variation among many soil parameters indicated in box plots and other exploratory analyses. We considered only one element value to be an outlier. One value of As was 140 mg/kg, while the next highest value was 8.5 mg/kg. This value was deleted from further analyses. In addition, one set of CEC data of 18 samples had high values that could not be valid for KSC soils, and these data were excluded from further analyses.

All soil parameters had distributions that differed from normality (Kolmogorov-Smirnov test, $p < 0.001$). Transformed values ($\log_{10}$) of Al, As, Ca, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, V, and Zn still differed from normality ($p < 0.05$); however, normality plots showed that the distributions were much improved such that analysis of variance could be conducted. One-way ANOVA is robust to modest departures from normality (Ray and Quinn, 1989).

Normality of distribution of CEC was improved by transformation ($\log_{10}$); however, normality plots indicated that bulk density was closer to normality than transformed values. Therefore, ANOVA was conducted on transformed values of CEC but on untransformed bulk density data. pH is expressed on a log scale and was not transformed further.

Discriminant analysis indicated significant multivariate differences among soil classes ($p< 0.001$) based on transformed elements (Al, As, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, K, Na, V, Zn), CEC, and bulk density.

Kruskal-Wallis tests indicated that all soil parameters differed among soil classes ($p< 0.001$). However, given the low frequency of detection of some elements, ANOVA was conducted only where >25% of values were above detection and for pH, bulk density, and CEC. All elements analyzed (Al, As, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, K, Na, V, Zn) were significantly different among types ($p < 0.001$), as were pH, bulk density, and CEC ($p <0.001$) (Table 6). Variances were not homogeneous except for Zn (Levene test, $p<0.05$); thus, the Games-Howell test was appropriate for examining multiple comparisons (Table 6).

Patterns of differences varied among elements and other parameters (Table 6). Calcium was high in coastal and disturbed soils, low in acid scrub and flatwoods, and intermediate in other types (Fig. 2A). Soil pH was highest in coastal soils and lowest in flatwoods (Fig. 2B). Aluminum had low concentrations in flatwoods, acid scrub, and coastal soils and higher values in other types (Fig. 3A). Iron was low in acid scrub and flatwoods soils and

TABLE 3. Soil classes with the series and land types in each.

Soil class and series	Soil subgroup
COASTAL	
Canaveral	Aquic Udipsamment
Palm Beach	Typic Udipsamment
Welaka	Spodic Quartzipsamment
ACID SCRUB	
Astatula	Typic Quartzipsamment
Cassia	Typic Haplohumod
Daytona	Entic Haplohumod
Orsino	Spodic Quartzipsamment
Paola	Spodic Quartzipsamment
Pomello	Arenic Haplohumod
St. Lucie	Typic Quartzipsamment
Satellite	Aquic Quartzipsamment
Tavares	Typic Quartzipsamment
COQUINA SCRUB	
Bulow	Typic Hapludalf
Cocoa	Psammentic Hapludalf
FLATWOODS	
Holopaw	Grossarenic Ochraqualf
Immokalee	Arenic Haplaquod
Myakka	Aeric Haplaquod
Myakka variant	Aeric Haplaquod
Pompano	Typic Psammaquent
Smyrna	Aeric Haplaquod
St. Johns	Typic Haplaquod
Wabasso	Alfic Haplaquod
Winder	Typic Glossaqualf
HAMMOCKS	
Bradenton, shallow variant	Typic Orchaqualf
Copeland	Typic Argiaquoll
Parkwood	Mollic Orchaqualf
Tuscawilla	Typic Orchaqualf
FRESHWATER WETLANDS	
Anclote	Typic Haplaquoll
Basinger	Spodic Psammaquent
Canova	Typic Glossaqualf
Chobee	Typic Argiaquoll
Felda & Winder	Arenic Orchaqualf/Typic Glossaqualf
Felda & Winder, ponded	Arenic Orchaqualf/Typic Glossaqualf
Floridana	Arenic Argiaquoll
Immokalee, depressional	Arenic Haplaquod
Myakka, ponded	Aeric Haplaquod
Pineda	Arenic Orchaqualf
Riviera	Arenic Glossaqualf
Samsula muck	Terric Medisaprists
St. Johns, ponded	Typic Haplaquod
Swamp	N/A
Tequesta muck	Arenic Glossaqualf
Valkaria	Spodic Psammaquent
SALTWATER WETLANDS	
Submerged Marsh	N/A

TABLE 3. Continued.

Soil class and series	Soil subgroup
Tidal Marsh	Hydraquents
Tidal Swamp	Hydraquents
Hydraquents	Hydraquents
CITRUS SCRUB	Acid Scrub and Coquina Scrub types
CITRUS HAMMOCK	Hammock types
DISTURBED	
Canaveral-urban land	Entisol
Galveston-urban land	Entisol
Urban land	Entisol
Quartzipsamments	Entisol
Arents	Entisol
Spoil Banks	Entisol
Dikes	Entisol
Made land	Entisol
Turnbull variant	Aquic Udipsamment

higher in other types (Fig. 3B). Magnesium, K, and Na levels were highest in saltwater wetlands and lowest in acid scrub (Fig. 4A, 4B, 4C). Lead concentrations were high in saltwater wetlands, low in acid scrub, coastal, and flatwoods soils, and intermediate in other types (Fig. 4D). Chromium, Cu, Mn, and Zn had higher concentrations in citrus scrub and citrus hammock soils and lower values elsewhere (Fig. 5).

Arsenic had higher concentrations in coastal and saltwater wetland soils and lower values elsewhere (Fig. 6A). Mercury was low in acid scrub and coastal soils and high in hammocks and freshwater wetlands (Fig. 6B). Vanadium was low in acid scrub and flatwoods, high in saltwater wetlands, and intermediate in other types (Fig. 6C).

Bulk density was low in flatwoods, hammock, freshwater wetland, and saltwater wetland soils and higher in the other types (Fig. 7A). Coastal, acid

TABLE 4. Area of soil classes.

Soil class	Area (hectares)	Percent of soil area
Coastal	1098.3	3.30
Acid Scrub	1556.9	4.76
Coquina Scrub	270.4	0.81
Flatwoods	10432.6	31.32
Hammocks	1990.1	5.97
Freshwater Wetlands	6154.3	18.48
Saltwater Wetlands	9626.2	28.90
Citrus Scrub	349.3	1.05
Citrus Hammock	640.0	1.92
Disturbed	1192.4	3.58

TABLE 5. Frequency (percent) of values greater than detection limits for chemical parameters in soils. Only parameters greater than detection limits in at least one sample are shown.

Parameter	All soils	Coastal	Acid scrub	Coquina scrub	Flatwoods	Hammocks	Freshwater wetlands	Saltwater wetlands	Citrus scrub	Citrus hammock	Disturbed
Sample Size	220	23	22	22	21	20	22	21	23	23	23
Aluminum	99.1	91.3	100	100	100	100	100	100	100	100	100
Arsenic	30.0	95.6	9.1	9.1	4.8	10.0	13.6	71.4	21.7	21.7	39.1
Barium	1.4	4.3	0	0	0	0	0	0	0	0	8.7
Cadmium	1.8	4.3	0	0	0	0	0	0	13.0	0	0
Calcium	100	100	100	100	100	100	100	100	100	100	100
Chromium	65.9	100	13.6	86.4	0	70.0	45.5	76.2	100.0	91.3	69.6
Copper	27.3	17.4	4.5	0	9.5	5.0	9.1	0	100	95.7	21.7
Iron	100	100	100	100	100	100	100	100	100	100	100
Lead	91.8	91.3	72.7	100	76.2	100	86.4	100	100	95.7	95.7
Magnesium	92.7	100	40.9	95.5	95.2	100	100	100	100	100	95.7
Manganese	84.5	100	77.3	100	19.0	95.0	59.1	90.5	100	100	100
Mercury (inorganic)	31.8	0	0	31.8	19.0	75.0	54.5	33.3	39.1	52.2	17.4
Potassium	64.5	91.3	13.6	59.1	33.3	70.0	45.5	100	87.0	69.6	73.9
Selenium	1.8	0	0	0	0	5.0	4.5	0	0	0	8.7
Silver	1.8	4.3	0	4.5	0	0	0	0	0	0	8.7
Sodium	89.5	100	72.7	100	85.7	85.0	95.5	100	91.3	91.3	73.9
Thallium	2.7	13.0	0	0	0	0	0	0	4.3	8.7	0
Vanadium	70.9	100	22.7	90.9	14.3	85.0	54.5	100	82.6	82.6	73.9
Zinc	59.1	56.5	31.8	45.5	38.1	55.0	59.1	28.6	100	91.3	78.3

scrub, and coquina scrub soils had low CEC values; CEC was higher in freshwater wetlands and hammocks (Fig. 7B).

Mean grain size was greatest in coastal and coquina scrub soils (Table 7) reflecting the shell fragments in these soils that are larger than the quartz grains that comprise much of the rest of the soil.

The first two axes of the PCA accounted for 62.8% of the explained variance (Fig. 8, 9). Cations (Na, K, Ca, Mg) and pH were related as was As (Fig. 8). The other elements were generally related but several groups were evident: 1) Al, Fe, and V; 2) Cu and Zn; and 3) Cr, Pb, and Mn. Soil classes (Fig. 9) arrayed along the first two axes. Acid scrub and flatwoods soils were associated with low elemental concentrations but high bulk density. Coastal and saltwater wetland soils were associated with high cations. Citrus scrub and citrus hammock soils were associated with high levels of Cu and Zn.

DISCUSSION—*Soil distribution*—Soil classes vary substantially in their extent across the KSC landscape. Flatwoods and wetlands predominate, reflecting the low, poorly drained topography. Most soils have not been obviously disturbed; current or past citrus agriculture has affected about 3% of the soil area, and disturbed soils constitute about another 3.6%. Most of the saltwater wetlands on KSC were impounded for mosquito control and variously managed (Rey et al., 1991). The effects on soil of impoundment or reconnection (Brockmeyer et al., 1997) are not understood.

Soil chemical and physical parameters—All the elements examined here occur naturally, but their levels may have increased anthropogenically; concentrations in KSC soils also reflect the origins of the soils (Davis, 1997; Scott, 1997) and subsequent changes from weathering and leaching. Florida soils have low concentrations of many elements (Shacklette and Boerngen, 1984). Sands of coastal dunes are mixtures of terrigenous and biogenic deposits. The terrigenous deposits are primarily quartz with small amounts of feldspar, heavy minerals, and phosphorite, while the biogenic deposits are carbonates, primarily shell material (Field and Duane, 1974). Past studies of KSC soils (Madsen, 1980; Stout, 1980; Schmalzer and Hinkle, 1992a; 1992b) have examined available or exchangeable concentrations and cannot be compared to the total concentrations analyzed here.

Calcium comprises about 3.6% of the earth's crust; however, Ca is mobile in the soil and readily leached (Paton et al., 1995). Calcium carbonate shell material is the initial source for most of the Ca in these soils. Thus, the young, coastal dune soils had the highest Ca levels. Disturbed soils often include dredged material high in shell content. Soils associated with coquina (coquina scrub, hammocks) also had relatively high Ca levels. Those soils most thoroughly leached, acid scrub and flatwoods, had the lowest Ca levels. Calcium is abundant in seawater (412 ppm, Mitsch and Gosselink, 1986) explaining the relatively high levels in saltwater wetland soils.

TABLE 6. Means and standard deviations (in parenthesis) of chemical parameters in soils. Only parameters greater than detection limits in at least one sample are shown. nd = all samples below detection limits. * indicates ANOVA significant ($p < 0.001$). Only parameters above detection limits in sufficient samples were analyzed. Data were transformed ($\log_{10}$) before analysis (except pH and bulk density). Multiple comparisons were made using Games-Howell tests. Soil classes not significantly different ($p > 0.05$) are indicated by the same letter following the mean.

Parameter	All soils	Coastal	Acid scrub	Coquina scrub	Flatwoods
Sample Size	220	23	22	22	21
Elements					
Aluminum*	1444.6	282.6	202.8	1001.6	164.7
(mg/kg)	(2576.4)	(262.7)	(306.8)	(678.2)	(84.6)
		A	A	C	A
Arsenic*	0.8	2.3	0.6	0.3	0.3
(mg/kg)	(1.1)	(1.3)	(1.8)	(0.5)	(0.1)
		A	B	B	B
Barium	13.1	10.0	11.1	10.3	13.0
(mg/kg)	(6.7)	(1.9)	(nd)	(nd)	(nd)
Cadmium	0.6	0.5	0.5	0.5	0.6
(mg/kg)	(0.3)	(0.1)	(nd)	(nd)	(nd)
Calcium*	16446	50044	150	22057	383
(mg/kg)	(36190)	(18497)	(135)	(65351)	(211)
		E	A	BCD	B
Chromium*	4.6	2.1	0.8	2.3	0.6
(mg/kg)	(6.3)	(0.6)	(1.2)	(1.3)	(nd)
		A	BE	A	B
Copper*	13.9	1.8	3.2	2.6	2.8
(mg/kg)	(27.0)	(1.0)	(2.4)	(nd)	(0.7)
		A	B	AB	B
Iron*	1283.5	1063.0	240.4	1511.8	144.1
(mg/kg)	(1909.3)	(209.6)	(421.5)	(883.9)	(81.3)
		B	A	B	A
Lead*	5.8	2.2	1.5	4.0	2.4
(mg/kg)	(11.3)	(0.9)	(0.8)	(1.6)	(2.5)
		AB	A	C	AB
Magnesium*	549.2	370.0	28.0	87.6	112.3
(mg/kg)	(1354.4)	(131.6)	(18.8)	(37.7)	(60.5)
		D	A	B	BC
Manganese*	25.8	11.3	2.5	54.2	0.9
(mg/kg)	(39.5)	(2.3)	(1.8)	(44.3)	(0.8)
		C	B	A	E
Mercury*	0.0157	0.006	0.005	0.008	0.007
(inorganic) (mg/kg)	(0.0262)	(nd)	(nd)	(0.005)	(0.003)
		A	A	AB	AE
Potassium*	229.0	58.4	42.6	74.0	57.0
(mg/kg)	(673.7)	(37.8)	(33.1)	(39.3)	(41.8)
		ABC	A	B	ABC
Selenium	1.2	0.7	1.1	1.0	1.2
(mg/kg)	(0.8)	(nd)	(nd)	(nd)	(nd)
Silver	1.3	1.0	1.1	1.1	1.2
(mg/kg)	(0.7)	(0.1)	(nd)	(0.5)	(nd)
Sodium*	1459.3	461.3	12.6	174.0	48.7
(mg/kg)	(6852.2)	(169.3)	(5.1)	(471.8)	(34.6)
		D	A	ABCG	BCG

TABLE 6. Extended.

Hammocks	Freshwater wetlands	Saltwater wetlands	Citrus scrub	Citrus hammock	Disturbed
20	22	21	23	23	23
2395.0	2315.9	2683.8	1172.2	1821.3	2491.3
(2382.4)	(3148.0)	(1997.6)	(919.4)	(1768.2)	(5863.6)
BC	BC	B	C	BC	BC
0.4	0.6	1.3	0.4	0.5	0.7
(0.4)	(0.6)	(1.1)	(0.3)	(0.7)	(0.7)
B	B	AC	B	B	BC
15.0	16.4	21.8	10.4	10.6	13.0
(nd)	(nd)	(nd)	(nd)	(nd)	(6.8)
0.7	0.8	1.0	0.6	0.5	0.5
(nd)	(nd)	(nd)	(0.4)	(nd)	(nd)
11278	9609	11627	2100	11099	43053
(20935)	(29489)	(18373)	(3060)	(24043)	(60942)
CD	CD	CD	D	CD	CE
3.5	3.1	4.5	12.2	11.8	3.9
(3.2)	(4.3)	(3.3)	(7.8)	(9.5)	(6.1)
A	AE	AC	D	DC	A
4.3	4.7	5.5	53.5	54.0	2.6
(3.8)	(4.8)	(nd)	(36.4)	(40.6)	(0.8)
BC	BC	C	D	D	AB
1717.5	1326.1	1504.8	1502.2	1984.8	1783.4
(1716.3)	(2361.4)	(1091.3)	(900.4)	(2368.4)	(4059.3)
B	B	B	B	B	B
6.2	5.1	16.6	9.7	5.8	5.1
(4.5)	(4.9)	(33.8)	(4.8)	(3.8)	(4.6)
CD	BC	CD	D	CD	BC
534.1	316.0	3291.0	232.6	377.4	288.9
(836.0)	(468.5)	(3151.2)	(189.3)	(328.3)	(343.3)
DE	BCD	F	CEG	DG	BD
14.7	9.6	10.1	82.0	58.7	7.9
(17.5)	(20.4)	(10.5)	(52.1)	(51.1)	(6.4)
C	BC	C	A	A	C
0.0396	0.0375	0.0179	0.012	0.0161	0.0108
(0.0523)	(0.0471)	(0.0162)	(0.0116)	(0.0158)	(0.0166)
C	CD	BCD	ACD	BCDE	AD
114.6	95.2	1631.0	94.6	121.7	72.7
(113.8)	(65.6)	(1620.5)	(110.7)	(121.0)	(54.6)
BC	AB	D	AB	AB	AB
1.5	1.7	2.1	1.0	1.0	1.2
(1.0)	(1.1)	(nd)	(nd)	(nd)	(0.6)
1.5	1.6	2.1	1.0	1.0	1.1
(nd)	(nd)	(nd)	(nd)	(nd)	(0.4)
168.5	169.4	13771	17.0	38.3	336.3
(227.8)	(311.2)	(18366)	(21.6)	(67.2)	(444.0)
C	BC	E	AF	FG	BC

TABLE 6. Continued.

Parameter	All soils	Coastal	Acid scrub	Coquina scrub	Flatwoods
Thallium	0.7	0.8	0.5	0.5	0.5
(mg/kg)	(0.5)	(0.8)	(nd)	(nd)	(nd)
Vanadium*	3.2	2.4	0.7	2.2	0.8
(mg/kg)	(4.5)	(0.5)	(0.5)	(1.0)	(0.6)
		B	A	B	A
Zinc*	15.1	6.6	5.2	5.0	7.7
(mg/kg)	(21.2)	(5.1)	(3.8)	(3.1)	(5.9)
		AB	A	A	AD
Other Parameters					
pH*	5.1	8.1	5.2	5.8	4.4
		A	C	DE	B
Bulk density*	0.96	1.19	0.99	1.05	0.72
(g/cm^3)	(0.27)	(0.13)	(0.14)	(0.16)	(0.15)
		A	B	AB	C
Cation exchange	14.0	2.5	2.9	3.8	17.8
capacity*	(14.2)	(1.5)	(1.6)	(2.3)	(7.4)
(meq/100g)	[n = 202]	[n = 16]	[n = 22]	[n = 22]	[n= 21]
		A	A	AD	BC

Magnesium makes up about 2.1% of the earth's crust (Paton et al., 1995) and is abundant in seawater (ca. 1300 ppm, Mitsch and Gosselink, 1986). The highest levels of Mg were in saltwater marshes reflecting the seawater source. Magnesium carbonate shell material is another source for Mg in these soils. Magnesium is mobile in most soils and readily leached. The highly leached, acid scrub soils had the lowest Mg levels.

Potassium comprises about 2.6% of the earth's crust (Paton et al., 1995) and is abundant in seawater (399 ppm, Mitsch and Gosselink, 1986). The highest levels were in saltwater marshes, reflecting the seawater source. Potassium is highly mobile and readily leached.

Sodium content of the earth's crust is about 2.8% (Marschner, 1986). Sodium is the most abundant cation in seawater (ca. 10,770 ppm, Mitsch and Gosselink, 1986). The highest levels in KSC soils were in saltwater marshes, reflecting that seawater source. The next highest, although much lower, levels were in coastal dune soils where salt spray provides a continuing input of Na (Ranwell, 1972). Sodium is highly mobile and readily leached from surface soils where precipitation is abundant (Paton et al., 1995). The lowest levels in KSC soils were in the highly leached, acid scrub soil.

Soil pH is affected by H^+ ions derived from rainfall, from carbonic acid formed by carbon dioxide and water in the soil environment, and from organic acids produced by decomposition (Brady, 1974; Birkeland, 1999). Soluble aluminum (Al^{3+}) also affects soil pH, particularly under acidic conditions. Sources of hydroxyl ions (OH^-) include reactions with cations, Ca^{2+},

TABLE 6. Continued and Extended.

Hammocks	Freshwater wetlands	Saltwater wetlands	Citrus scrub	Citrus hammock	Disturbed
0.7	0.8	1.0	0.6	0.9	0.5
(nd)	(nd)	(nd)	(0.4)	(1.0)	(nd)
5.2	3.7	7.4	2.0	4.5	3.4
(5.5)	(5.6)	(6.3)	(1.1)	(5.1)	(6.3)
BC	B	C	B	BC	B
12.8	13.6	7.7	49.2	29.2	11.8
(23.7)	(11.1)	(4.8)	(36.3)	(23.1)	(11.4)
AB	BDEF	AE	C	CF	ABEF
4.9	4.8	6.3	6.5	6.1	5.8
DE	CE	D	DE	DE	D
0.74	0.72	0.71	1.13	1.18	1.11
(0.24)	(0.26)	(0.33)	(0.15)	(0.09)	(0.21)
C	C	C	AB	A	AB
23.5	28.7	18.3	19.4	11.3	10.6
(18.6)	(19.7)	(9.0)	(17.2)	(8.1)	(9.6)
[n = 20]	[n = 22]	[n = 21]	[n = 17]	[n = 23]	[n = 18]
BC	C	BC	BC	B	BD

Mg^{2+}, K^+, and Na^+ (Brady, 1974; Birkeland, 1999). Coastal soils of KSC are alkaline where calcium carbonate shell material is abundant, while other soil types are slightly to strongly acid. Leaching of basic cations from older soils has contributed to their acidity. Coquina scrub soils that have shell material deeper in the soil profile are less acid than acid scrub soils that lack this buffering. The agricultural types (citrus scrub, citrus hammock) are less acidic than the original soil types. This may be due to liming (Brady, 1974) or to irrigation with groundwater high in carbonates.

Aluminum is a major constituent of the earth's crust (Kabata-Pendias and Pendias, 1984). Alumino-silicate clays are produced by weathering and are a major constituent of many soils (Brady, 1974; Birkeland, 1999). Although the clay fraction of KSC soils is small (Huckle et al., 1974; Baldwin et al., 1980), Al is present throughout. The lowest levels of total Al in KSC soils were in flatwoods and acid scrub probably due to intense weathering (Birkeland, 1999). Low levels of Al in coastal soils may reflect low amounts in the original sediments. All KSC soils were low in Al relative to other Florida soils (Table 8). Availability of Al in soil is pH dependent, with its mobility increasing below a pH of 5.5 (Brady, 1974).

Iron is a major constituent of the lithosphere; its abundance in rock types ranges from 0.4% of limestones to 10.0% of ultramafic rocks (Kabata-Pendias and Pendias, 1984). Typical values in soils range from 0.5% to 5.0% (5,000–50,000 ppm) (Brady, 1974). Soils on KSC had low levels of Fe compared to this and compared to other Florida soils (Table 8). Acid scrub and flatwoods were much lower than other types. Soils of these classes are

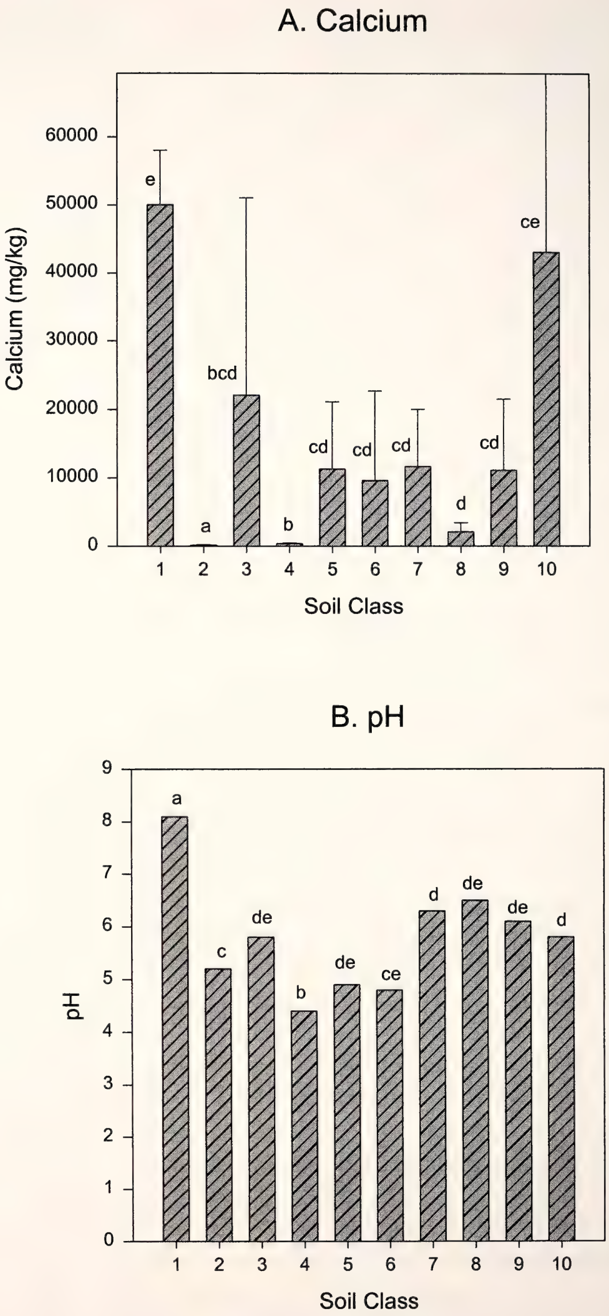
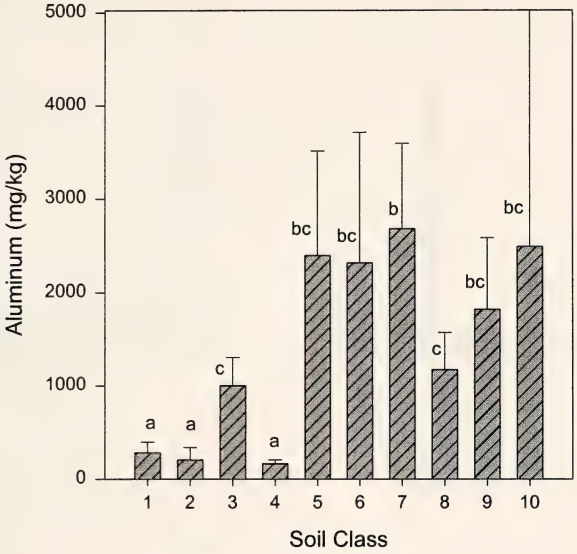


FIG. 2. Calcium (A) and pH (B) in soil classes. Soil classes are 1-Coastal, 2-Acid Scrub, 3-Coquina Scrub, 4-Flatwoods, 5-Hammocks, 6-Freshwater Wetlands, 7-Saltwater Wetlands, 8-Citrus Scrub, 9-Citrus Hammock, and 10- Disturbed. Error bars are 95% confidence intervals. Bars with the same letter are not significantly different (Games-Howell test, $p > 0.05$).

A. Aluminum



B. Iron

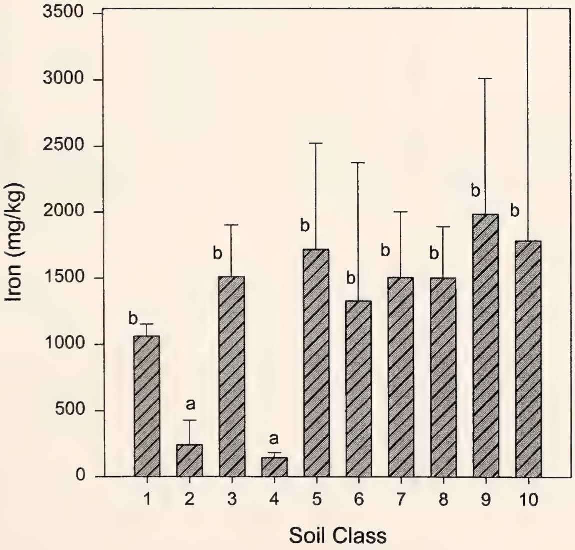


FIG. 3. Aluminum (A) and iron (B) in soil classes.

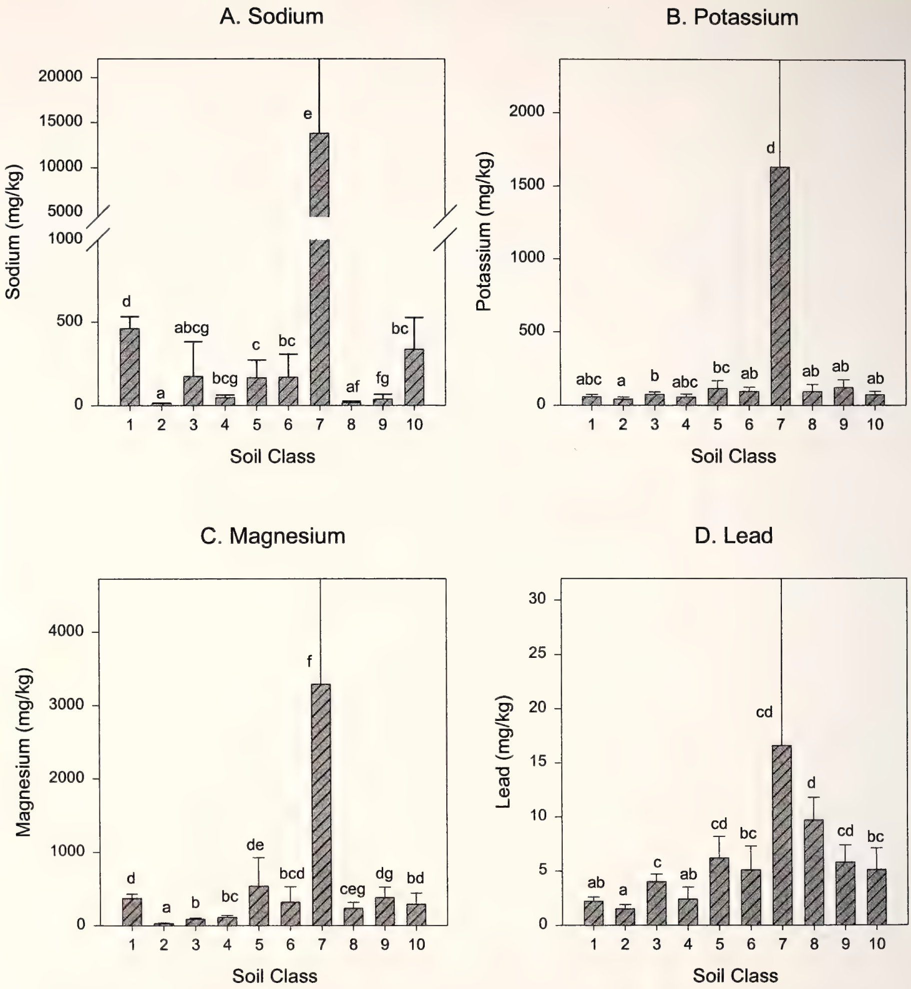


FIG. 4. Sodium (A), potassium (B), magnesium (C), and lead (D) in soil classes.

mainly Spodosols (podzols) (Table 3). Formation of podzols involves intense leaching of the surface horizon removing iron and transporting it to deeper soil layers (Paton et al., 1995).

Chromium occurs in a variety of rock types, but it is most abundant in serpentine (Kabata-Pendias and Pendias, 1984); Cr is generally low in sandy soils (Table 9) and in Florida soils (Table 8). Most KSC soils had low to very low values of Cr. Chromium concentrations in agricultural types (citrus scrub, citrus hammock) were higher; Cr occurs in phosphate fertilizers, and this may account for its greater abundance in agricultural soils here. Sources of Cr contamination include industrial wastes, mining and metal processing, wood preservatives, and sewage sludge (Kabata-Pendias and Pendias, 1984; Evangelou, 1988).

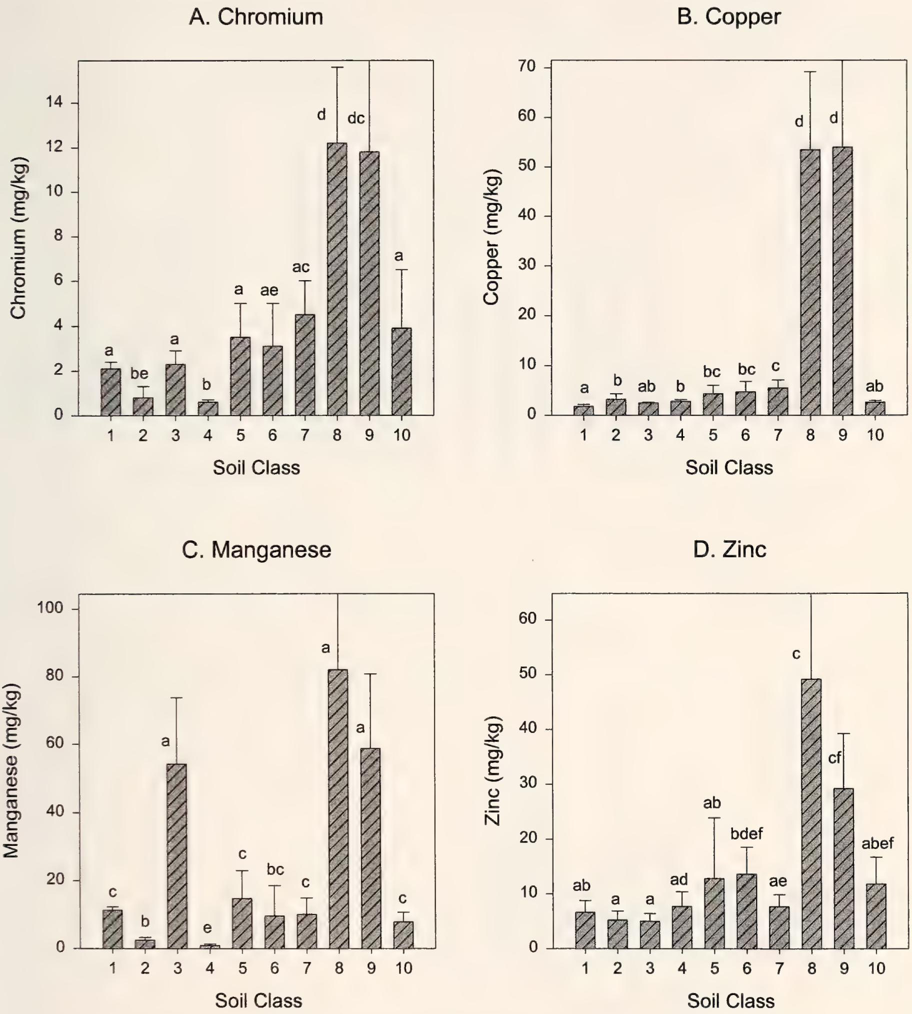


FIG. 5. Chromium (A), copper (B), manganese (C), and zinc (D) in soil classes.

Copper is most abundant in mafic rocks. Worldwide mean background values of Cu in soil range between 6–60 ppm (Kabata-Pendias and Pendias, 1984) with sandy soils at the low end of the range (Table 9). Copper concentrations in Florida soils are typically low (Table 8). Copper is concentrated in surface soils due to bioaccumulation and recent anthropogenic sources; these sources include mining and smelting emissions, fertilizers, fungicide sprays, algicides, wood preservatives, and municipal and agricultural wastes (Kabata-Pendias and Pendias, 1984; Evangelou, 1988). Copper levels in KSC soils were low, but the agricultural types (citrus scrub, citrus hammock) had higher values probably due to past applications of Cu-containing fungicides or fertilizers. Copper is relatively immobile in the soil

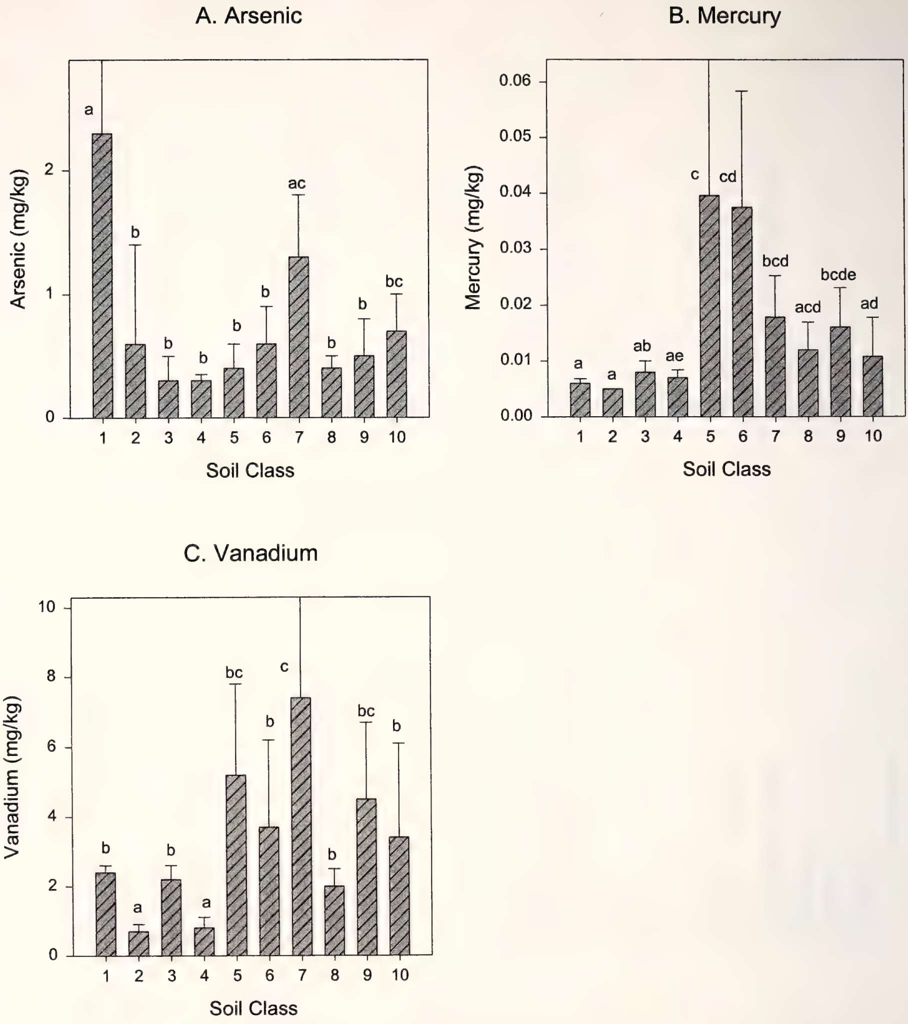


FIG. 6. Arsenic (A), mercury (B), and vanadium (C) in soil classes.

(Kabata-Pendias and Pendias, 1984; McBride, 1994), so elevated levels in agricultural soils may persist.

Manganese is one of the most abundant trace elements, but it has its greatest concentrations in mafic rocks (Kabata-Pendias and Pendias, 1984). Soil levels of Mn vary, although those reported for sandy soils (Table 9) are lower than in soils from mafic rocks (Kabata-Pendias and Pendias, 1984). Typical values for Florida soils are relatively low (Table 8). All KSC soils were relatively low in Mn; however, agricultural soils (citrus scrub, citrus hammock) were higher than other types. Manganese is found in sewage sludge and phosphate fertilizers (Kabata-Pendias and Pendias, 1984), suggesting a fertilizer source of Mn for the agricultural soils. Other sources

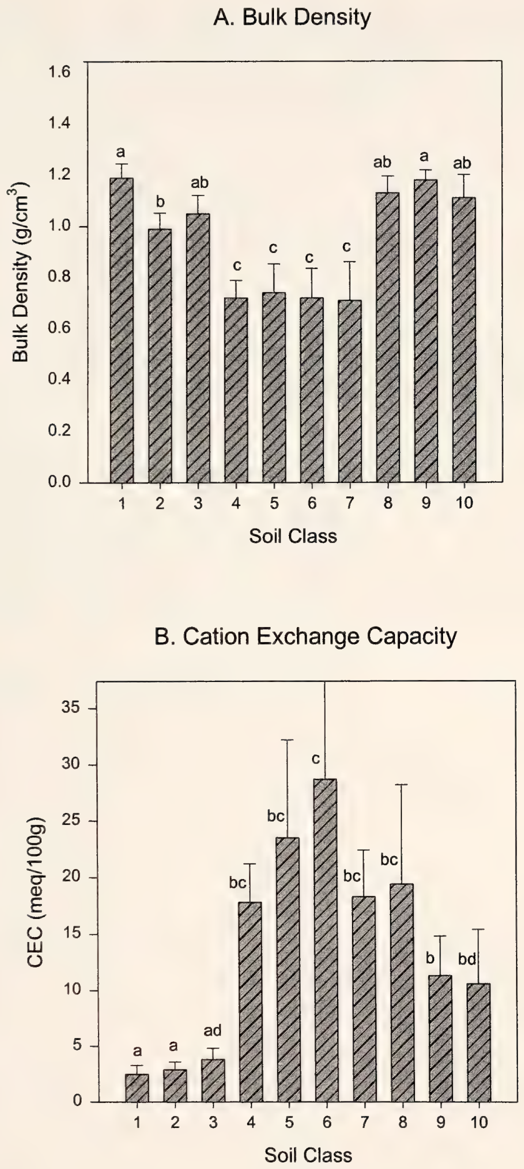


FIG. 7. Bulk density (A) and cation exchange capacity (B) in soil classes.

include mining and smelting (Evangelou, 1988). Manganese levels in coquina scrub soils were also relatively high. The chemistry of Mn in the soil is complex with cycles of oxidation and reduction, solution, and precipitation under varying soil conditions (Kabata-Pendias and Pendias, 1984; McBride, 1994). Manganese is often associated with Fe in soils, and Fe was also high in coquina scrub soils.

Zinc is widely distributed in rock types and soils (Kabata-Pendias and

TABLE 7. Mean grain size and classification of soil types.

Soil class	Mean grain size (phi)	Mean grain size (mm)	Wentworth classification	Unified soil classification
Coastal	1.7	0.31	Medium Sand	Fine Sand
Acid Scrub	2.6	0.17	Fine Sand	Fine Sand
Coquina Scrub	1.7	0.31	Medium Sand	Fine Sand
Flatwoods	2.2	0.22	Fine Sand	Fine Sand
Hammocks	2.8	0.14	Fine Sand	Fine Sand
Freshwater Wetlands	2.6	0.17	Fine Sand	Fine Sand
Saltwater Wetlands	2.85	0.14	Fine Sand	Fine Sand
Citrus Scrub	2.2	0.22	Fine Sand	Fine Sand
Citrus Hammock	2.65	0.16	Fine Sand	Fine Sand
Disturbed	2.45	0.18	Fine Sand	Fine Sand

Pendias, 1984, Table 9), but it is usually associated with sulfide minerals (McBride, 1994). Concentrations in Florida soils are typically low (Table 8). Zinc contamination is related to mining and smelting, wood preservatives, and to agriculture where it is a component of fertilizers and some pesticides (Kabata-Pendias and Pendias, 1984; Evangelou, 1988). Levels of Zn in KSC

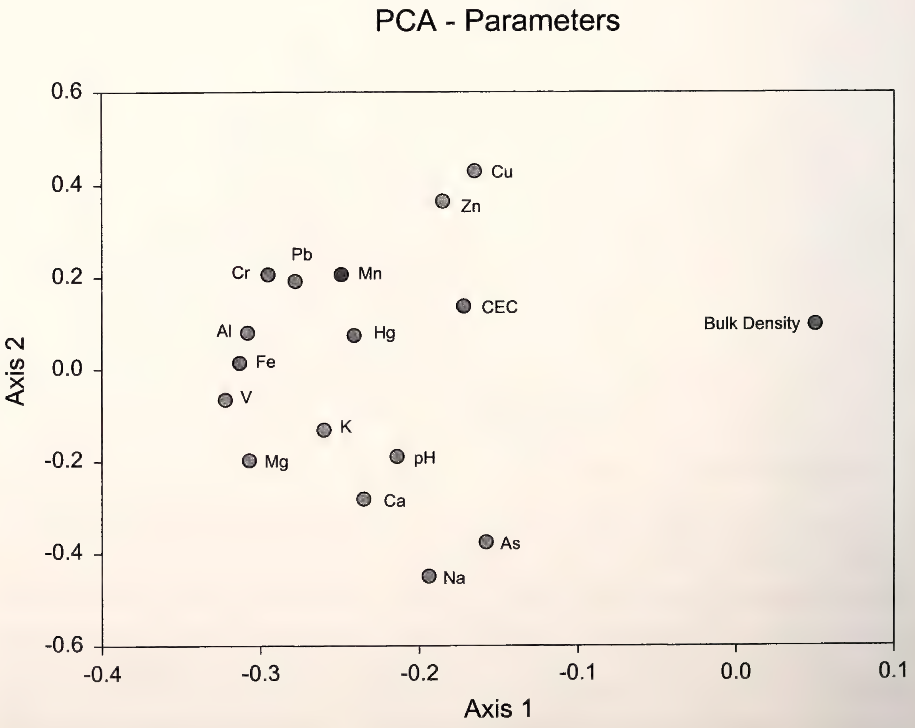


FIG. 8. Principal components analysis of soil chemical and physical parameters. Shown are the first two axes.

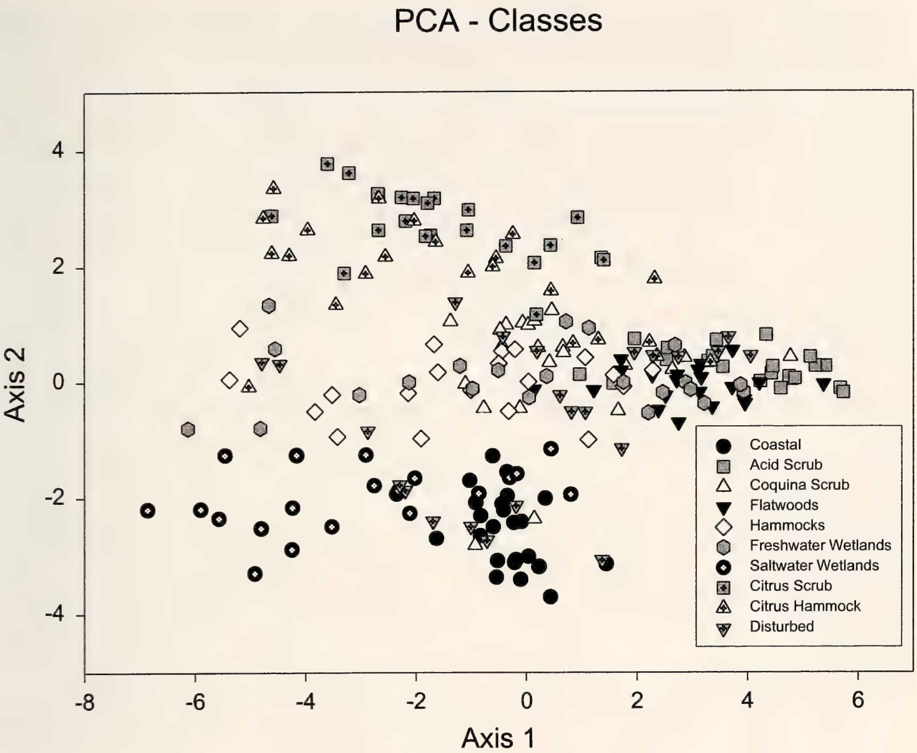


FIG. 9. Scores of samples within soil classes along first two axes of principal components analysis.

soils were generally low, but levels in the agricultural types (citrus scrub, citrus hammock) were higher suggesting sources in fertilizers or pesticides.

Arsenic is widely distributed in rock types (Kabata-Pendias and Pendias, 1984). The range of background concentrations in soils is fairly wide (Table 9). Levels in KSC soils are toward the low end of the range of As values for sandy soils but within typical Florida values (Table 8). Values in coastal and saltwater wetland soils were higher than the other types; As was also higher in groundwater in the Dune (coastal) and Marsh subaquifers (Schmalzer and co-workers, 2000). Arsenic is often associated with organic matter in soil (Kabata-Pendias and Pendias, 1984). Significant contamination sources include industrial pollution, coal combustion, mining and metal processing, arsenic pesticides, and wood preservatives (Kabata-Pendias and Pendias, 1984; Evangelou, 1988); As also occurs in some phosphate fertilizers (Kabata-Pendias and Pendias, 1984). Arsenic was once used in livestock dips to control ticks, and this resulted in localized contamination (Upchurch and Randazzo, 1997).

Lead is concentrated in acid magmatic rocks and clay sediments. Lead content of U.S. soils averages 20 ppm with similar ranges in a variety of soils (Kabata-Pendias and Pendias, 1984, Table 9). Typical Florida soils have

TABLE 8. Concentrations of selected elements in typical surface soils of Florida (Shacklette and Boerngen, 1984). Samples were taken 20 cm below the surface.

Element	Concentration (mg/kg)
Aluminum	<20,000
Antimony	<1
Arsenic	<3
Barium	<200
Beryllium	<1
Calcium	<3000
Chromium	<20
Cobalt	<3
Copper	<10
Iron	<10,000
Lead	<10
Magnesium	<1500
Manganese	<150
Mercury	<0.032
Nickel	<5
Potassium	<6800
Selenium	<0.2
Sodium	<2000
Vanadium	<20
Zinc	<17

TABLE 9. Background levels of trace elements in surface soils. Data are from Kabata-Pendias and Pendias (1984)*.

	Sandy soils—United States		Podzols and sands—different countries	
Element	Range	Mean	Range	Mean
Antimony	**	**	0.05–1.33	0.19
Arsenic	<0.1–30.0	5.1	1.1–28.9	2.4–5.8
Barium	20–1500	400	180–780	**
Beryllium	<1–3	1.9	**	**
Cadmium	**	**	0.01–1.80	0.07–0.43
Chromium	3–200	40	1.4–530	21–110
Cobalt	0.4–20	3.5	0.1–65	**
Copper	1–70	14	1–52	8–16
Lead	<10–70	17	2.3–47.5	10.4–57.0
Manganese	7–2000	345	9–1900	**
Mercury	<0.01–0.54	0.08	0.01–0.70	0.04–0.06
Nickel	<5–70	13.0	1–52	7–11
Selenium	0.005–3.5	0.5	0.05–1.32	0.14–0.27
Vanadium	7–150	47	10–91	**
Zinc	<5–164	40.0	3.5–146	24–42

* ppm dry weight.

** indicates no data reported.

less than 10 mg/kg Pb (Table 8). Lead was widely distributed in KSC soils, but Pb levels were relatively low. Levels in saltwater wetlands were higher than other types. In surface soils, Pb is associated with organic matter; saltwater wetlands tend to accumulate organic matter at the surface. Lead contamination is widespread, particularly in surface soils; sources of contamination have included mining and smelting, fossil fuels, paint, automobile exhaust, sewage sludge, pesticides, and fertilizers (Kabata-Pendias and Pendias, 1984; Evangelou, 1988).

Mercury concentrations in rock types are greatest in organic-rich shales. In soils, concentrations are greatest in organic soils (Kabata-Pendias and Pendias, 1984) with lower levels in acid, sandy soils (Table 9). Florida soils are generally low in Hg (Table 8). Most KSC soils were low in Hg; soil classes with more organic matter (hammocks, wetlands) tended to have higher Hg concentrations, consistent with its affinity for organic matter. Sources of Hg contamination include mining and metal processing, some chemical industry, sewage sludge, coal combustion, and formerly the application of fungicides containing Hg (Kabata-Pendias and Pendias, 1984; Stevenson, 1986). The formation of organomercury compounds, particularly methyl mercury, is important to the distribution and cycling of Hg (Schlesinger, 1991).

Vanadium content of rock types varies widely, but it is most abundant in mafic rocks (Kabata-Pendias and Pendias, 1984). Sandy soils contain relatively low amounts of V (Table 9, Kabata-Pendias and Pendias, 1984) as do Florida soils (Table 8). Vanadium tends to be associated with organic matter in soil (McBride, 1994). Levels of V were low in most KSC soils; levels were somewhat higher in soils with more organic matter (wetlands, hammocks). Sources of V contamination include processing of mineral ores and combustion of coal and fuel oil; it also occurs in some phosphate fertilizers (Kabata-Pendias and Pendias, 1984).

Antimony, Be, Co, and Ni were never above detection limits in KSC soils, reflecting low background levels and no widespread contamination. The crustal abundance of Sb and Be is low (Kabata-Pendias and Pendias, 1984) as are their levels in sandy soils (Table 9) and in Florida soils (Table 8). Sources of Sb and Be contamination include industrial pollution, smelters, and coal combustion. Cobalt and Ni are most abundant in ultramafic rocks such as serpentine (Kabata-Pendias and Pendias, 1984). Levels of both in sandy soils (Table 9) and in Florida (Table 8) are low. Sources of Co and Ni contamination include metal smelting, paint, and combustion of oil and coal (Kabata-Pendias and Pendias, 1984; Evangelou, 1988). Nickel is also found in some phosphate fertilizers (Kabata-Pendias and Pendias, 1984).

Barium, Cd, Se, Ag, and Tl were above detection limits in only a few KSC soils, reflecting low background levels and no widespread contamination. Levels of Ba and Se in Florida soils are typically low (Table 8). Typical background values of Cd in soil are < 0.5 ppm (Kabata-Pendias and Pendias, 1984, Table 9). Background values of Ag in soil can range from 0.03 to 3.2 ppm (Kabata-Pendias and Pendias 1984). Background levels of Tl range between 0.02 to 2.8 ppm in surface soils of the U.S. (Kabata-Pendias and Pendias, 1984). These elements have various anthropogenic sources (Kabata-Pendias and Pendias, 1984; Evangelou, 1988).

Values of CEC vary with clay content and mineral species and organic matter content (Birkeland, 1999). All KSC soils have little clay content, so organic matter is the main determinant of CEC. Coastal, acid scrub, and coquina scrub soils had very low CEC values consistent with the low organic matter content of these soils, while values in hammocks and wetlands, where organic matter accumulation is greater, were substantially higher.

Bulk density varies with the relative proportion of solid organic matter in the soil and with soil porosity. Typical values for soil surface (A) horizons range from 0.7–2.0 (Birkeland, 1999). High organic matter decreases bulk density, but intense cultivation increases bulk density through loss of organic matter (Brady, 1974). In KSC soils, bulk density was lowest in wetland soils, hammocks, and flatwoods where organic matter accumulates in surface soils and was highest in coastal and scrub soils with little organic matter accumulation. Cultivation of citrus hammock soils appears to have increased bulk density, probably through loss of organic matter.

Mean grain size was greatest in coastal and coquina scrub soils where shell fragments are common and larger than the quartz grains that comprise much of the soil. Grain size was less in acid scrub soils where weathering has removed shell fragments. Hammocks and wetlands had the smallest mean grain size, perhaps reflecting accumulation of finer grain material in these types. The Wentworth classification reflected these differences better than the Unified Soil classification (Table 7).

Principal components analysis summarized relationships among soil parameters. Cations were correlated due to common origin in saltwater or shell material. Many of the other elements were retained or accumulated in soils with more organic matter that have lower bulk densities. These elements were correlated to each other and negatively related to bulk density. Trace elements in fertilizers or pesticides (e.g., Cu, Zn) were also correlated due to common origin.

Natural variation among KSC soil classes is related to several factors of soil formation (Jenny, 1980), particularly time, topography, and parent material. Where all factors except time are relatively constant, soils can be arranged in a chronosequence (Jenny, 1980). General trends among chronosequences include leaching of carbonates, accumulation, and eventual decline of organic matter and nitrogen (Jenny, 1980). Clay formation and illuviation occur over time in soils with weatherable minerals (Markewich et al., 1989). However, in well sorted, quartzose sand, such as much of the Coastal Plain of the eastern United States, podzolization leads to the formation of Spodosols (Markewich et al., 1986; 1989; Birkeland, 1999). Podzolization can occur rapidly (Paton et al., 1976; Birkeland, 1999) after calcium is removed from the profile (Paton et al., 1995). Rates of calcium leaching have been determined for some chronosequences (Jenny, 1980) but not for dunes in central Florida. Once formed, Spodosols may persist for long periods (Markewich et al., 1986).

The clearest chronosequence comparison for KSC is between the coastal and acid scrub soils. The loss of cations and leaching of Fe and Mn are associated with soil ageing. Soils of intermediate age and leaching status occur on Cape Canaveral (Huckle et al., 1974; Schmalzer, unpublished data). More detailed examination of chronosequences across this landscape requires better understanding and dating of the formation of this complex barrier island.

SUMMARY—Soil chemical and physical properties varied across the KSC landscape in patterns related to topography, parent material, age, and human influences. The ten soil classes used here were successful in describing major features of that variation.

Elements varied in frequency of detection and concentrations. Concentrations were generally low, consistent with the origin and degree of leaching of the soils. Four elements (Cr, Cu, Mn, and Zn) had higher levels in agricultural sources, suggesting sources in fertilizers or pesticides. Cations (Mg, K, Na) were high in saltwater wetland soil. Young, coastal soils were high in calcium. Intensively leached acid scrub and flatwoods soils were very low in cations and other elements. Soils where organic matter accumulates retained higher concentrations of many elements.

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IMPACTS OF THE INTRODUCED FERN, *LYGODIUM MICROPHYLLUM*, ON THE NATIVE VEGETATION OF TREE ISLANDS IN THE ARTHUR R. MARSHALL LOXAHATCHEE NATIONAL WILDLIFE REFUGE

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Abstract: Lygodium microphyllum *is a fern native to Asia that has been introduced into south Florida and poses a potential threat to native communities. Fern ladders grow over vegetation and appear to blanket and change the existing vegetation structure and composition. This study examined vegetation species richness and percent cover in ground cover, shrub layer, and overstory in one 4 × 5 m plot on each of 10 tree islands in the Arthur R. Marshall Loxahatchee National Wildlife Refuge. Five of the islands had dense infestations of* L. microphyllum *and five had very low or no infestation. Species richness was similar between infested islands and uninfested islands; however, percent cover of native species was higher in uninfested plots than in infested plots in the overstory (64% compared to 3%), shrub (33% compared to 4%), and ground cover (66% compared to 9%). This study illustrates the impact that* L. microphyllum *can have on native tree island communities in south Florida.*

The genus *Lygodium* contains approximately 40 species and is pantropical in distribution. It also occurs in several temperate areas including South Africa, New Zealand, Japan, and the Eastern United States (Tryon and Tryon, 1982). *L. microphyllum* is native to Southeast Asia, Malaysia, Australia and tropical Africa. Within its native range, *L. microphyllum* is reported to colonize wet areas and open places, to tolerate full sun, and to form dense growth covering other vegetation (Edie, 1978).

L. microphyllum was reported as adventive in Martin and Palm Beach Counties Florida in the late 1950s (Beckner, 1968). Nauman and Austin (1978) described large colonies in the same counties. *L. microphyllum* is now widely spread throughout the southern Florida pennisula (Pemberton and Ferriter, 1998).

L. microphyllum was first noted in the interior of the Arthur R. Marshall Loxahatchee National Wildlife Refuge, in western Palm Beach County, in 1989 (Bailey and Thomas, Jr., 2000). In 1993 aerial surveys showed it on a few tree islands in the central and north-central portion of the refuge. By 1995, 12% or approximately 7,300 ha of the refuge was infested and by 1997 *L. microphyllum* was observed in an additional 1,875 ha (Bailey and Thomas, Jr., 2000) for a total of approximately 9,175 ha. In some areas of the refuge *L. microphyllum* has completely covered tree islands, forming fern ladders that extend to the tops of the trees and dense mats in the understory. Visual observations suggest that *L. microphyllum* is a significant threat to native plant and animal communities by changing vegetation structure and increasing the potential for crown fires (Langeland and Burks, 1998).

The impact of *L. microphyllum* on native vegetation is related to the unusual morphology and specialization of climbing leaves in the genus *Lygodium.* The stem is a slender, branched rhizome that commonly grows underground or in rotting wood. Fronds develop on the dorsal side of the rhizome. The elongate, strong, wiry rachis bears alternate bladeless primary pinnae that are reduced to short stalks. At the end of each stalk is a pair of opposite secondary pinnae and a terminal bud which is normally dormant. The secondary pinnae bear leaflets which may be variously lobed or subdivided. Growth of the frond is indeterminant in that the primary axis continues to grow for many meters. If a frond is damaged, a terminal bud of a primary pinnae may develop into another indeterminant axis, allowing continued elongation of the frond (Proctor, 1989; Punetha, 1987).

Studies by Mueller (1982a; 1982b; and 1983) on *L. japonicum* reveal additional climbing specializations of the frond. A growing tip displays a circumnutation or a searching motion but is not thigmotropic. Rate of growth of the tip of a supported leaf continues at a rapid rate (3.4–6.5 cm/day) for an extended period although unsupported leaves tend to stop growing. Delayed leaflet expansion reduces the weight and bulk of the climbing portion of the frond. The leaves of *Lygodium* are different from those of typical ferns and show a structural similarity with climbing shoots of many seed plants.

The narrow but highly elongate frond of *L. microphyllum* may extend high into the canopy. A dense growth of *L. microphyllum* consists of numerous individual fronds extending from the ground into higher vegetation and intertwining to form a thick blanket. The arrangement of the blanket of fronds is tent-like and clearly blocks much light to underlying vegetation layers. The result may be change in native vegetation community composition. This study quantifies the impacts of *L. microphyllum* on native tree island vegetative communities.

METHODS—This study was conducted in the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Loxahatchee) in western Palm Beach County, Florida. Loxahatchee is approximately 57,324 ha of deep peat wetland with organic soils of 2.4 to 3.7 m deep. It is a remnant of original northern Everglades, and has large areas of open sloughs, wet prairies and sawgrass strands. Within this matrix are thousands of tree islands (areas of slightly higher elevation where woody plants are able to colonize). Native tree islands range from less than 0.1 to 125 ha in size with approximately 85% of them less than 0.13 ha (Brandt et al., 2000). The overstory of most islands is dominated by *Ilex cassine, Persea palustris,* and *Myrica cerifera. Chrysobalanus icaco, Cephalanthus occidentalis* and *Salix caroliniana* also are found in the shrub layer and overstory. Ground cover is generally made up of ferns (Pope, 1991; Stone, 1978). Tree islands provide habitat for a wide range of plants, invertebrates, and vertebrates (Brandt unpublished data, Gawlik and Rocque, 1998) and are an important component of the Everglades system.

Vegetation community composition and structure were quantified using quadrat sampling on 10 tree islands located in a 1,300 ha area within the northern third of Loxahatchee where both heavily infested and uninfested tree islands occur. Discreet tree islands less than approximately 50 m in length that had either dense or no to very little *L. microphyllum* infestation were the types of islands targeted for this study. This was done to quantify the vegetation on islands at the extremes of infestation. Study islands were selected by driving into the area of heavy infestation and searching for small islands that had either a dense canopy of *L. microphyllum* as indicated by fern ladders growing up over the tops of the tree island vegetation, or no evidence of *L. microphyllum.* Searches were conducted generally along north to south transects; however, dense vegetation made it difficult to keep searches systematic. Latitude and longitude of each island were recorded using a global positioning system. One 4 × 5 m quadrat was located 10 m from the midpoint of the south edge of the island. Quadrat size was selected to correspond with sampling being conducted on tree islands in other areas of the Everglades (D. Masson, 1999). Only one plot per island was selected so that the number of different islands sampled could be maximized. Though this did not allow us to examine inter island variability in vegetation it did allow us to compare between island vegetation patterns. Data collected in each quadrat included: a species list for each layer, percent cover of each layer, i.e., ground cover (< 1 m), shrub layer (1–2 m), and overstory (> 2 m); percent cover of each species in each layer (in 5% increments); and a general description of the plot.

Species richness, evenness (Pielou, 1969), and Simpson's Index of diversity were calculated for each plot and for each layer and compared between infested and uninfested islands using a one tailed t-test after testing for normality and equal variances. Species richness and evenness are the components of the species diversity indices which help to describe the organization of the community. Communities with a high diversity index are more complex and have many equally or nearly equally abundant species present (Brower and Zar, 1977). Communities with a high evenness value are dominated by one or a few species, while those with low evenness values have more equitable species abundance.

Community composition differences were examined between heavily infested islands and uninfested islands using Multi-Response Permutation Procedure (MRPP) and Bray-Curtis ordination in PC-Ord (McCune and Mefford, 1995). MRPP is a non-parametric procedure for testing the hypotheseis of no difference between two a prioi groups. In this case we used it to test if vegetative communities on infested islands were different than communities on uninfested islands. MRPP is similar to discriminant analysis; however, it does not require that the data are multivariate normal or have homogeneity of variances (Zimmerman et al., 1985).

Ordination is a method of arranging samples in relation to one or more coordinate axes so that their relative positions to the axes and to each other provides maximum information about their ecological similarity (Ludwig and Reynolds, 1988). It provides a way to visually display these ecological similarities. Bray-Curtis ordination, also known as Polar ordination, was specifically developed to analyze plant community data (Bray and Curtis, 1957). We used it in this study to examine the ecological similarity between the vegetation communities on infested islands and uninfested islands. If the vegetation communities between the two types of islands are similar, the sample plots will be clustered along the axes. Differences will be illustrated by separation on one or both of the two axes.

RESULTS AND DISCUSSION—Twenty different species were identified from the 10 islands (Table 1). Overall species richness was similar between the infested and uninfested islands (17 and 16 respectively). Richness for individual plots averaged 8 (range 6 to 10) for uninfested plots and 9 (range 7 to 12) for infested plots. Evenness was significantly lower in the infested plots than in the uninfested plots when all layers were analyzed together ($t = 4.217$, $df = 8$, $p = 0.001$), as was diversity ($t = 5.00$, $df = 8$, $p = 0.0005$). When the layers were analyzed separately, evenness was only sig-

TABLE 1. Species found in 4 × 5 m plots on tree islands in the Arthur R. Marshall Loxahatchee National Wildlife Refuge during December 1999 and January 2000 and the number islands on which each occurred.

Scientific name	Common name	Number of plots
Acrostichum danaeifolium	Leather fern	1
Blechnum serrulatum	Swamp fern	10
Cephalanthus occidentalis	Buttonbush	1
Ilex cassine	Dahoon holly	6
Lygodium microphyllum	Lygodium	7
Myrica cerifera	Wax myrtle	9
Nephrolepis exaltata	Sword fern	3
Osmunda cinnamomea	Cinnamon fern	4
Osmunda regalis	Royal fern	1
Peltandra virginica	Green arrow arum	2
Persea palustris	Swamp bay	9
Rapanea punctata	Myrsine	6
Sarcostemma clausum	Milkweed vine	2
Schinus terebinthifolius	Brazillian pepper	4
Smilax laurifolia	Smilax	3
Thelypteris interrupta	Willdenow's shield fern	3
Thelypteris palustris	Marsh shield fern	1
Tillandsia usneoides	Spanish moss	1
Vitis rotundifolia	Grape vine	4
Woodwardia virginica	Chain fern	4

nificantly lower in the shrub layer, while diversity was lower in the shrub and overstory layers (Table 2). Similar species were observed on infested and uninfested islands; however, the abundance of native species was lower where the abundance of *L. microphyllum* was higher. In the overstory, the median (± SD) percent cover of native species was significantly higher on the uninfested islands than on the infested islands, 67% ± 18.2 compared to 3% ± 2.4, respectively (Mann-Whitney U test, $p = 0.0079$). The same pattern was observed in the shrub layer and ground cover (30% ± 16.2 compared to 4% ± 1.7, $p = 0.0079$; and 76% ± 28.3 compared to 3% ± 9.0, $p = 0.0159$, respectively). On some infested islands species were represented by one individual with few leaves or a few etiolated individuals. Over time, species may be eliminated resulting in overall loss in richness.

Results of the MRPP indicate that there were significant differences between the infested and uninfested plots for each layer and for all layers combined ($p = 0.002$ for all tests, $T = -5.5$, -5.8, -5.1, and -5.8 for ground cover, shrub layer, overstory, and all layers combined, respectively). The first axis of the Bray-Curtis Ordination explained 74.4%, 43.7%, 49.7%, and 61.7% of the variation in the data for analyses of ground cover, shrub layer, overstory, and all layers together, respectively. This axis represents the percent cover of *L. microphyllum.* All plots infested with *L. microphyllum* fell in the bottom left quarter of the ordination plots in all of the analyses (Figure 1). The second axis explained an additional 12.1%, 20.4%, 22.3%,

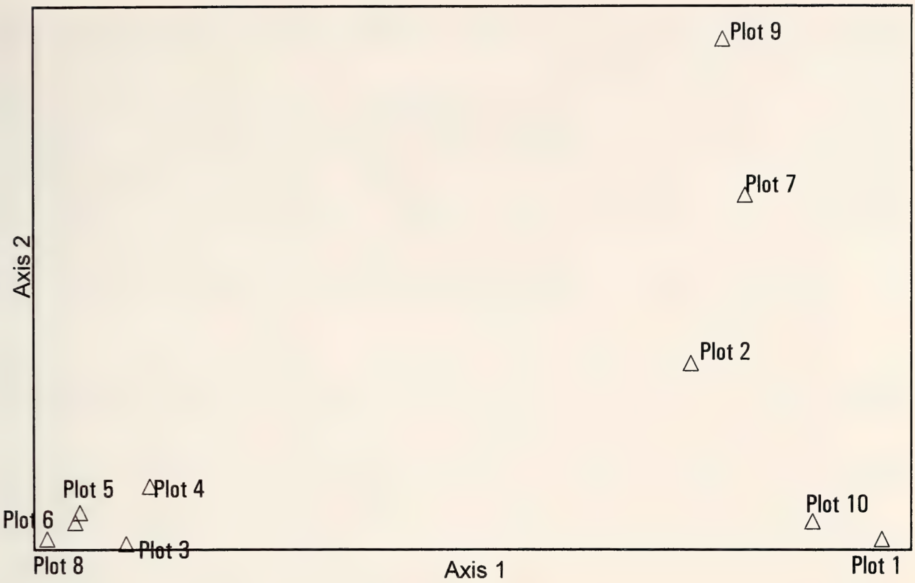

FIG. 1. Plot of the results of the Bray-Curtis Ordination performed on all layers combined for plots infested (3, 4, 5, 6, 8) and uninfested (1, 2, 7, 9, 10) with *L. microphyllum.* Axis 1 represents the level of *L. microphyllum* infestation and Axis 2 represents the native vegetation community composition.

and 14.8% for the aforementioned analyses, respectively and illustrates the natural variation in percent cover of native vegetation on tree islands.

The impact of *L. microphyllum* is to change the composition of the native community, decreasing the amount of native vegetation present and creating islands that are more homogeneous (less variation in vegetation composition). The natural variation in plant diversity and evenness are replaced by stands more strongly dominated by *L. microphyllum.* Plants such as *I. cassine, M. cerifera,* and *P. palustris* that bear fruit that are food for birds are being covered and eventually replaced by a fern that probably has little food value. Insect communities (another important prey item for birds and lizards) also may change in response to the changes in the vegetation. In addition, the dense ladders and mats change the structure of the islands, decrease light penetration, make it hard to penetrate into the interior, and may make it difficult for species such as deer, raccoons, marsh rabbits, or turtles to use the islands as foraging, resting, or nesting sites. We do not know exactly how long *L. microphyllum* has been on the sampled islands; however, based on aerial surveys, it is likely that dense infestations have been present for five years. It will be important to gain a better understanding of the timing of the impacts of *L. microphyllum* so that control efforts can be initiated before major changes have occurred to the native communities.

In summary, *L. microphyllum* has significant impacts on native plant communities and may alter the overall ecological integrity of the Everglades system by first changing vegetation communities, and subsequently the wildlife that use these communities.

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EVALUATION OF ECOSYSTEM ENHANCEMENT BASED ON GROWTH RATES OF CENTRARCHID FISHES

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ABSTRACT: *A critical component of ecosystem restoration is the ability to evaluate restoration success. Fishes have been identified as useful indicators of biotic integrity in flowing ecosystems, because they integrate watershed conditions at relevant spatial and temporal scales. In this paper we evaluated the usefulness of characteristics of individual fish (allometric relationships and growth rates) as potential metrics for use in the analysis of ecosystem enhancement and/or restoration projects. We evaluated the effects of ecosystem enhancement on two components of individual fitness of largemouth bass, bluegill and redear sunfish (family Centrarchidae): (1) growth exponent* b*—the slope of log-linear relationship of wet mass on standard length and (2) growth rates within two control pools and one enhanced pool of the channelized Kissimmee River ecosystem, central Florida, USA. Persistence of low dissolved oxygen in the enhanced pool and broad performance curves of the three species produced limited levels of response. Nonetheless, our analyses indicate allometric W-SL relationships and growth rates of fishes, two quick and inexpensive measures, potentially integrate ecosystem enhancement effects, and therefore warrant further research as metrics for evaluation of ecosystem enhancement and restoration.*

HUMANS have adversely affected flowing-water ecosystems in a variety of ways, including water extraction, channelization, introductions of nonnative species, and discharge of pollutants. Gore and Shields (1995) outlined human impacts on major temperate floodplain rivers of the world, and Allan and Flecker (1993) implicated habitat loss and degradation as the primary threat to aquatic life in rivers and streams. The global extent and potential effects of these impacts have stimulated efforts to restore floodplain river ecosystems (Bayley, 1995).

A critical component of ecosystem restoration is the ability to evaluate restoration success (Kondolf and Micheli, 1995; Simenstad and Thom, 1996). Karr (1981) and Karr and co-workers (1986) identified fishes as excellent indicators of ecosystem restoration, because they integrate watershed conditions at much broader spatial and temporal scales than microbes or invertebrates. Additionally, allometric characteristics of individual fish (i.e., body condition, growth rates) have been used to indicate habitat quality and/

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or stress levels affecting fishes (Janssen and Giesy, 1984; Adams, 1990a; 1990b; Rice, 1990; Goede and Barton, 1990; Khan, 1999; Mills et al., 2000).

Growth rates and weight-length relationships vary among centrarchid populations and reflect conditions of the local habitat (Carlander, 1977, Nibbelink and Carpenter, 1998; Olson et al., 1998). The equation $W = kL^b$ is commonly used in analysis of fish growth, where W is mass (grams), k is a constant, L is length (millimeters), and *b* is the growth exponent (Anderson and Neumann, 1996). This relationship can be $\log_{10}$ transformed to yield the log-linear relationship $W = \log k + b \log L$. Zaret (1980) termed the growth exponent *b* a 'component of fitness,' because individuals with larger *b* values are in better condition (more plump) and are expected to have higher fitness (Danylchuk and Fox, 1994; Rakitin et al., 1999). Furthermore, species-specific growth exponent *b* (Zaret, 1980; Safran, 1992; Jepsen et al., 1999; Luecke et al., 1999), condition factor K (Le Cren, 1951; Mustafa, 1978; Brown and Murphy, 1991; Weisberg and Burton, 1993; Jonas et al., 1996), growth rate (Osenberg et al., 1988; Weisberg and Burton, 1993; Jepsen et al., 1999), and relative weight W_r (Wege and Anderson, 1978; Murphy et al., 1990; Jonas et al., 1996) of fishes have been used to evaluate habitat quality among disjunct water bodies. All of these studies typically infer fishes in high quality habitat have larger growth exponents or higher condition values. Fishes in better condition are believed to experience rapid growth, outgrow the risk of predation more quickly, and gain selective advantages in intraspecific competitions that result in increased fitness for the individual (Matthews, 1998). However, plasticity in fish life-histories may confound simple interpretations (Roff, 1984; Reznick et al., 1990, 1996; Hutchings, 1993).

In this paper, we apply the species-specific growth exponent *b* and growth rate of fishes as indicator metrics in the analysis of an ecosystem enhancement project. The specific objectives of our study were to examine the effect of ecosystem enhancement (Kissimmee River Pool B Demonstration Project) on the growth exponent *b* and growth rate of three species of centrarchid fishes, while testing the usefulness of these measures in restoration evaluation.

Study site—Prior to 1961, the Kissimmee River ecosystem (central Florida, USA) was composed of a 2–3 km wide mosaic of wetland habitats flanking a shallow river channel that meandered 166 km from Lake Kissimmee to Lake Okeechobee (Fig. 1). Seasonal water level variation and protracted floodplain inundation characterized the floodplain river ecosystem (Toth, 1990; 1993; Koebel, 1995; Toth et al., 1995; 1998). Between 1961

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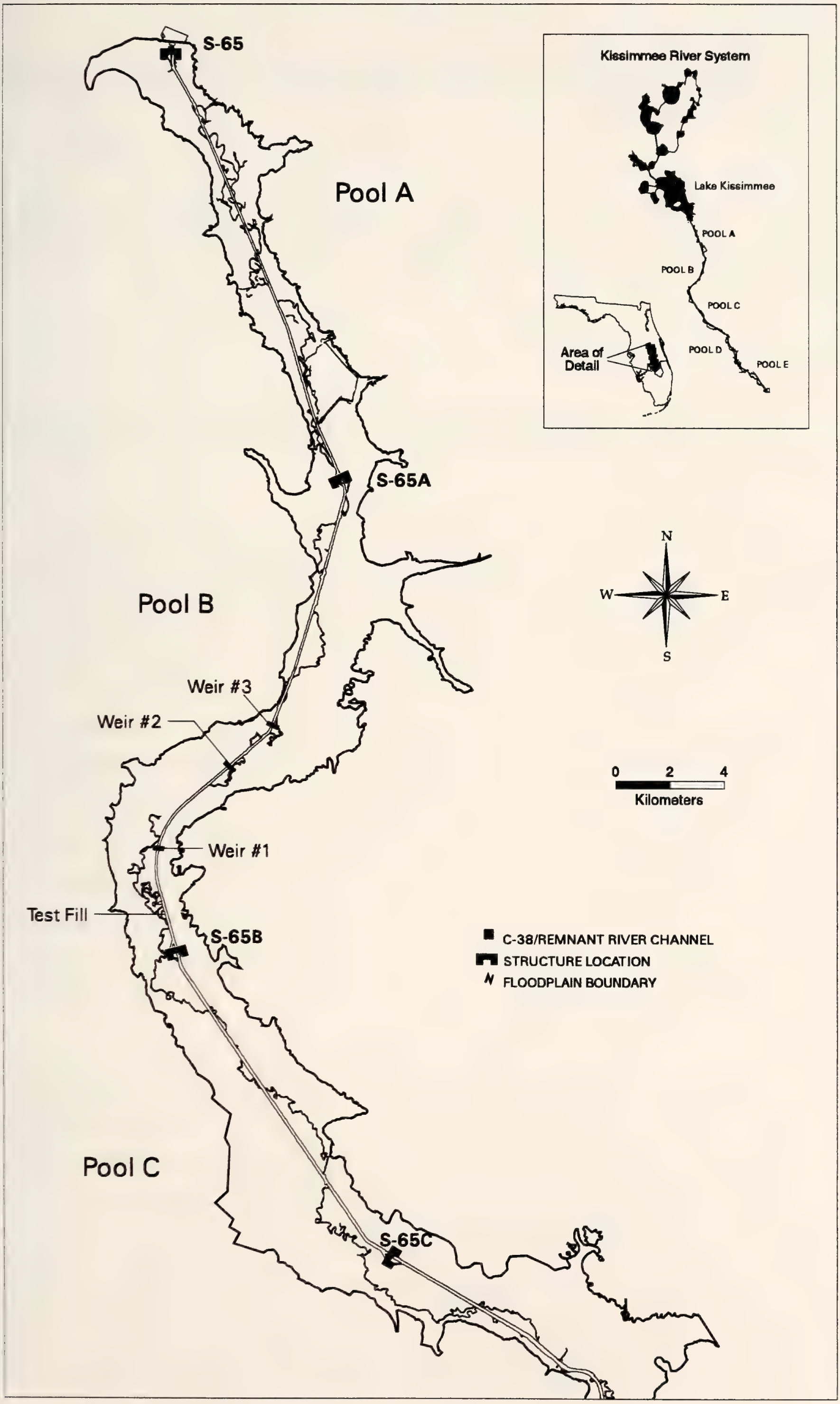
FIG. 1. Location of Pools A, B, and C in the channelized Kissimmee River with weirs and test-fill site indicated.


S-65
Pool A
Kissimmee River System
Lake Kissimmee
POOL A
POOL B
POOL C
POOL D
POOL E
Area of Detail
S-65A
N
W
E
S
Pool B
Weir #3
Weir #2
0
2
4
Kilometers
Weir #1
Test Fill
S-65B
C-38/REMNANT RIVER CHANNEL
STRUCTURE LOCATION
FLOODPLAIN BOUNDARY
Pool C
S-65C

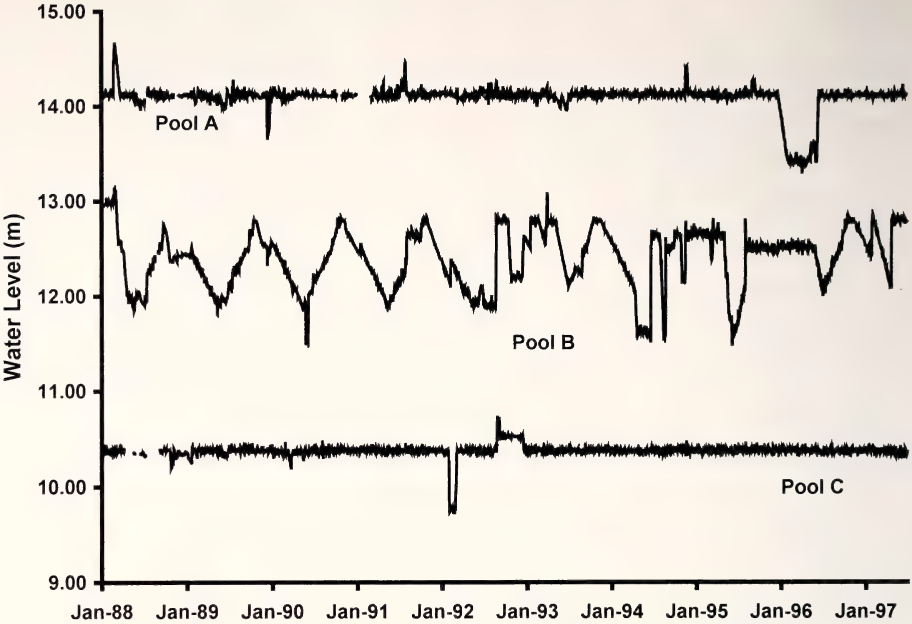


FIG. 2. Hydrographs for Pools A, B and C for period of record: January 1988 to June 1997.

and 1972, the river was channelized and a 56-km long, 100-m wide, 9-m deep canal (C-38) replaced the natural river channel as the principal pathway for discharge. Additionally, gated spillways were used to compartmentalize the canal into five segments, or pools, beginning with the upstream Pool A through the downstream Pool E (Fig. 1). Approximately two thirds of the floodplain wetlands were drained, covered with sediment dredged while forming the canal, or converted to canal (Koebel, 1995). Remnant river channels became stagnant side channels, and remnant floodplain habitats were subjected to water level stabilization due to stringent flood control regulations (Toth et al., 1997).

Pool B Ecosystem enhancement—The SFWMD initiated the 1984 Pool B Demonstration Project (Demonstration Project) to evaluate the feasibility of the planned Kissimmee River ecosystem restoration (Loftin, 1990; Toth, 1993). The Demonstration Project consisted of four components, of which two were designed to ameliorate channelization-related impacts: (1) re-establish water-level fluctuation and (2) re-establish flow through three remnant river channels (Toth, 1993; Koebel, 1995). These modifications occurred wholly within Pool B of the channelized Kissimmee River (Fig. 1).

Pool B water level fluctuation (Fig. 2) and backwater effects of weir installation affected 1080 hectares of floodplain habitat, and re-inundated 526 hectares of previously drained floodplain (Toth, 1993). Installation of three notched weirs across the C-38 canal (Fig. 1) diverted flow through three remnant river channels reestablishing fluvial processes within 9 km of remnant river channel (Toth, 1996). Because weirs were notched to maintain recreational navigation through the C-38 canal, flows were diverted into remnant river channels only during moderate to high discharges and backwater effects were punctuated with rapid recession rates (Fig. 2), which led to two major fish kills (Toth et al., 1990; Koebel, 1995).

Further enhancement within Pool B resulted from a 1994 pilot dechannelization project that backfilled 300 meters of the C-38 canal downstream of weir 1 (Fig. 1). This effort re-exposed 5.2 ha of historic floodplain by excavating deposited spoil material from original canal construction to refill the canal (Toth, 1996). Additionally, the frequencies of flows through the lower remnant river channel were increased because the pilot dechannelization effectively diverted the low discharges that previously passed through the navigation notch of the weir. These hydrologic effects resulted in more natural (i.e., riverine) hydrogeomorphology and increased habitat diversity in the lower section of Pool B (Toth, 1996).

The pre-channelized Kissimmee River fish community was composed of species that typically prefer slow moving water, and utilize floodplain habitats for feeding, reproducing, and as refugia from predation (FGFWFC, 1957; Lee et al., 1980; Trexler, 1995). Floodplain availability was vital to ecosystem function because the pulsed flows linked terrestrial, riparian and aquatic communities (Junk et al., 1989; Gladden and Smock, 1990; Winemiller, 1990). The inundated floodplain probably functioned similar to other floodplain systems by providing spawning habitat (FGFWFC, 1957; Bull et al., 1994; Scheaffer and Nickum, 1986) and refuge from predation (Savino and Stein, 1982). Periodic draining and flooding of floodplain habitats can increase overall productivity of river/floodplain ecosystems (Bayley, 1991), and in unmodified systems, this floodplain production is exported seasonally to the river channel in the form of forage fish and invertebrates that subsidize the river channel food web (Toth, 1990; *sensu* Polis et al., 1997).

Channelization altered various ecosystem functions including processes that influence river channel and floodplain production (Toth, 1990). In addition to loss of floodplain wetlands (approximately 14,000 ha) and associated primary and secondary production, loss of continuous flows and sandy substrates, decreases in forage organisms (invertebrates and small fish), and water level stabilization negatively affected local fisheries (Bull et al., 1991; 1994; Toth, 1990; 1993). Channelization further affected aquatic fauna because channelization resulted in seasonally depressed dissolved oxygen levels. Summertime dissolved oxygen levels frequently fall below 2 mg/L due to increased groundwater inputs and decreased physical mixing of the water (Koebel, 1995). The Demonstration Project partially alleviated many of these negative effects of channelization. Nonetheless, depressed summertime dissolved oxygen levels continue to constrain aquatic biota within the enhanced Pool B (Fig. 3; Bull et al., 1991; 1994; Koebel et al., 1998).

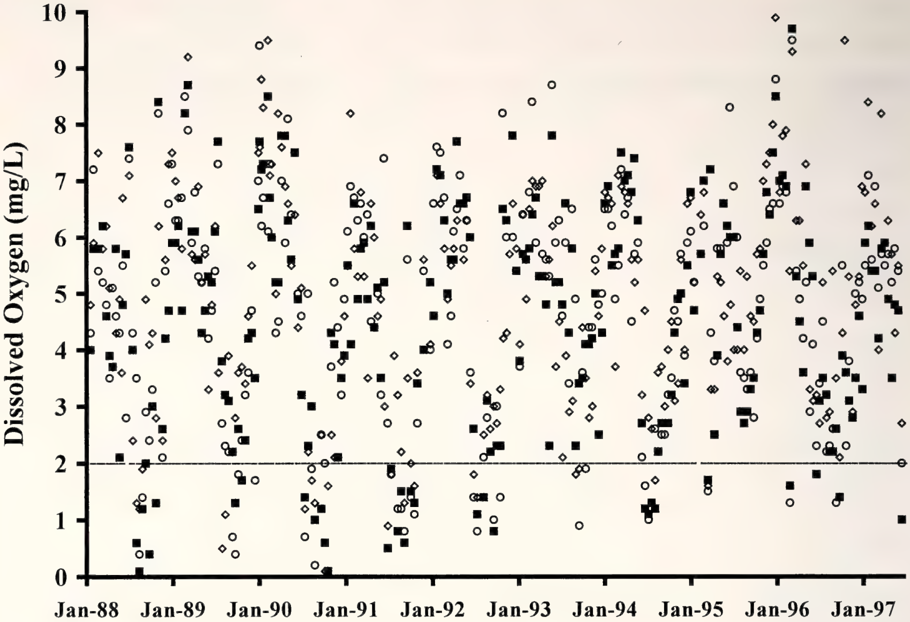


FIG. 3. Dissolved oxygen values for surface water samples collected between January 1988 and July 1997. Note the presence of points for each of the three pools below the horizontal line (<2.0 mg/L), which indicates very poor abiotic conditions. Pool A ◇; Pool B ■; Pool C ○.

Although Pool B ecosystem enhancements were limited in scope, changes in habitat quality and biological communities within Pool B were realized. Natural channel morphology, including a shifting sand substrate, was restored in the three remnant river channels adjacent the weirs (total of 9 km of river channel), and rheophilic invertebrate taxa replaced lentic taxa in affected remnant river channels (Toth, 1993; 1996). During high water events bluegill sunfish (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*) and redear sunfish (*Lepomis microlophus*) were observed or collected from inundated floodplain habitats (Bull et al., 1991; 1994). Electrofishing samples indicated the enhanced pool had higher relative abundances of largemouth bass and sunfishes (including bluegill and redear) than the control pools (Furse et al., 1996). Additionally, aquatic invertebrates and small-bodied fishes were found to be exported from enhanced floodplain habitats to the river channel during falling water periods (Toth, 1990). Thus, hydrologic enhancement re-established energy transfer pathways and other critical functional attributes that were lost due to channelization. However, the effects of these enhancements on higher trophic levels have not been fully examined.

In this paper, we evaluate whether ecosystem enhancement efforts in Pool B were sufficient to alter the growth exponent *b* and growth rates of fishes. Previous researchers found alterations in habitat quality resulted in altered growth rates, condition factor and survival of fishes (Dudley, 1974; Olson et al., 1998; Nibbelink and Carpenter, 1998; Khan, 1999; Ogutu-Ohwayo, 1999; Mills et al., 2000). Here, we evaluate the effects of ecosystem enhancement on two components of individual fitness for bluegill sunfish, largemouth bass and redear sunfish (family Centrarchidae), from three pools of the channelized Kissimmee River (Fig. 1): (1) growth exponent *b*, the slope of log-linear relationship of wet mass on standard length, and (2) growth rates. We predict the growth exponent *b* and growth rates of fishes will increase (significantly greater growth exponent *b*, length at age, and maximum size) within the enhanced pool (Olson et al., 1998; Khan, 1999; Mills et al., 2000). Persistent seasonal dissolved oxygen minima within the enhanced pool, however, may constrain the expression of these expectations (Stewart et al., 1967; Brett and Groves, 1979; Cuenco et al., 1985; Neill and Bryan, 1991; Buentello et al., 2000).

METHODS—*Field collection*—We collected fishes from randomly located transects adjacent to littoral vegetation in both remnant river channel and canal locations in Pools A, B and C of the channelized Kissimmee River. Fishes were collected using boat-mounted electrofishing gear during December 1996–January 1997 and June 1997. Each specimen was given a unique code and identified to species. Fish lengths were measured as standard length (SL), which is defined as the distance from the most anterior part of the fish to the posterior end of the hypural plate (Anderson and Neumann, 1996). SL, measured to the nearest mm, and wet mass, (W) ± 2.5 g, were recorded for each individual. Sagittal otoliths were removed, tagged with the individual's code, and stored for later analysis.

Otolith analysis—We estimated the age of each fish by counting the annular rings on the right sagittal otoliths from collected fish. Each otolith was placed in a black watch-glass, immersed in glycerin, then examined under reflected light using a dissecting microscope fitted with a micrometer. When the right sagittal otolith was not available, the left member was analyzed. Under reflected light, alternate hyaline and opaque zones on sagittae were visible and used to determine annual cycles of fast and slow growth, respectively.

Each author produced an age estimate for each fish sampled. All otoliths were examined independently by each author, i.e., neither investigator had prior knowledge of the other researcher's estimates. Corroboration of age estimates (number of annuli) between the independent samples was high (>96%), with all disagreement resulting from diffuse banding within the most interior opaque zone. In all cases, agreement was established after re-examination of the sample in question; therefore, all sampled fish are included in analyses and results that follow.

Data analysis—For each of the three species, individuals representing a broad range of size classes were collected from the three pools; however, analyses were limited to size and age classes common to all three pools. Therefore, weight / length analyses were performed on individuals within the following size ranges: bluegill 70–190 mm, largemouth bass 103–402 mm, and redear 83–210 mm (Table 1, Fig. 4), and length / age analyses were performed on individuals within the following age classes: bluegill 1–4 annuli, largemouth bass 0–5 annuli, and redear 1–4 annuli (Fig. 5).

We evaluated variations in the growth exponent *b*, the slope of the log-linear relationship of W on SL. Both Zaret (1980) and Safran (1992) suggested analyses using the growth exponent *b* were more appropriate than those using condition factor (K), because $b > 3$ for most centrarchid species and populations (Carlander, 1977). Pool-specific growth rates were computed using linear and von Bertalanffy growth function relationships of SL on age (Equation 1)

TABLE 1. Summary of the relationship between wet mass (W) and standard length (SL) by species among pools. Data were $\log_{10}$ transformed for regression analyses. Values in parentheses are standard errors. * = $p < 0.05$. Slopes with the same letter are not significantly different ($p > 0.05$) within species.

		Standard length (mm)		Weight (g)					
	n	Mean	Range	Mean	Range	Intercept (*k*)	Slope (*b*)	r^2	Least squared means (std. err.)
				Bluegill					
Overall	158	127.7	70–185	103	7–264	−5.01	3.28*	0.97	
Pool A	58	125.8	70–190	98	14–300	−4.68	3.12*a	0.98	1.83 (0.009)
Pool B	55	124.7	71–185	99	7–280	−5.58	3.54*b	0.98	1.82 (0.009)
Pool C	45	134.0	70–185	116	12–264	−4.66	3.12*a	0.98	1.83 (0.010)
				Largemouth Bass					
Overall	203	240.5	103–402	405	18–1450	−4.78	3.05*	0.99	
Pool A	68	227.0	103–402	335	18–1450	−4.81	3.06*c	0.99	2.40 (0.007)
Pool B	73	250.4	106–402	453	25–1650	−4.80	3.06*c	0.98	2.41 (0.007)
Pool C	62	243.5	103–394	424	24–1475	−4.70	3.02*c	0.99	2.42 (0.007)
				Redear					
Overall	81	137.7	83–210	117	14–410	−4.77	3.15*	0.96	
Pool A	26	142.1	83–210	134	18–410	−4.61	3.07*d	0.92	1.91 (0.016)
Pool B	39	135.0	84–210	103	18–280	−4.85	3.18*d	0.99	1.91 (0.013)
Pool C	16	137.1	84–205	122	14–358	−4.91	3.22*d	0.98	1.92 (0.021)

$$L_t = L_\infty(1 - e^{-k(t-t_0)}) \qquad (1)$$

where L_t is length at age t_t, L_∞ is the length a fish would reach if it grew indefinitely (asymptotic length), and k and t_0 are constants. We used adjusted r^2 values to evaluate improvements of von Bertalanffy estimates over linear estimates, because adjusted r^2 values correct for expected increases in r^2 resulting from additional independent variables in the model (Sokal and Rohlf, 1981).

Species-specific analyses were conducted for all tests. Statistical analyses were computed using SAS software (SAS, 1990). We used least-squares regression to estimate linear or log-linear relationships, and analysis of covariance was used to test first for homogeneity of slopes and then equality of intercepts among pools. We then used the least squares means option to test for equality of the dependent factor among pools while accounting for variation in the covariate. Significance was set at $\alpha = 0.05$ for all tests (Sokal and Rohlf, 1981). We evaluated two *a priori* planned contrasts: 1) enhanced (Pool B) versus control pools (Pools A and C), 2) comparisons between control pools (Pool A versus Pool C).

Because our analyses are based on the manipulation of an individual pool (Pool B), there was no replication in our comparative study. Interpretation of non-replicated research should be based on two factors: 1) is the system different after the manipulation, and 2) is the difference a result of the manipulation (Carpenter and Kitchell, 1993; Mittelbach et al., 1995). Although we can not definitively accept or reject our hypotheses (Hurlbert 1984), we view significant treatment effects (Pool B $\neq$ Pool A and Pool C) as lending support to our hypotheses (Carpenter and Kitchell, 1993).

RESULTS—Similar numbers and sizes (SL) of fishes were evaluated from each pool (Fig. 4, Table 1); however, these numbers do not reflect relative abundance within the pools. Log-linear relationships of W on SL were highly significant ($p<0.0001$) for all three species (Table 1). Log-linear relation-

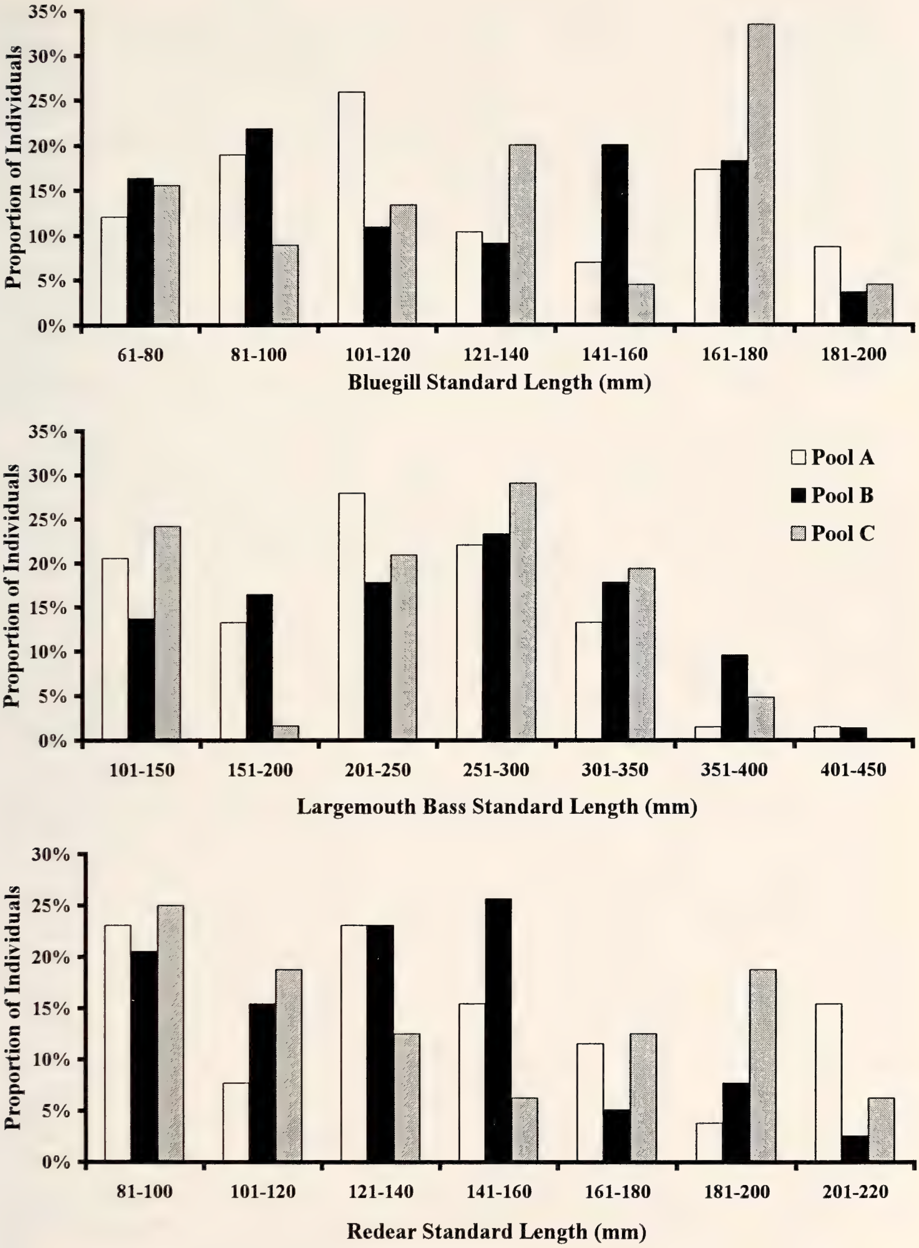


FIG. 4. Length frequency distributions for bluegill, largemouth bass, and redear for Pools A, B, and C.

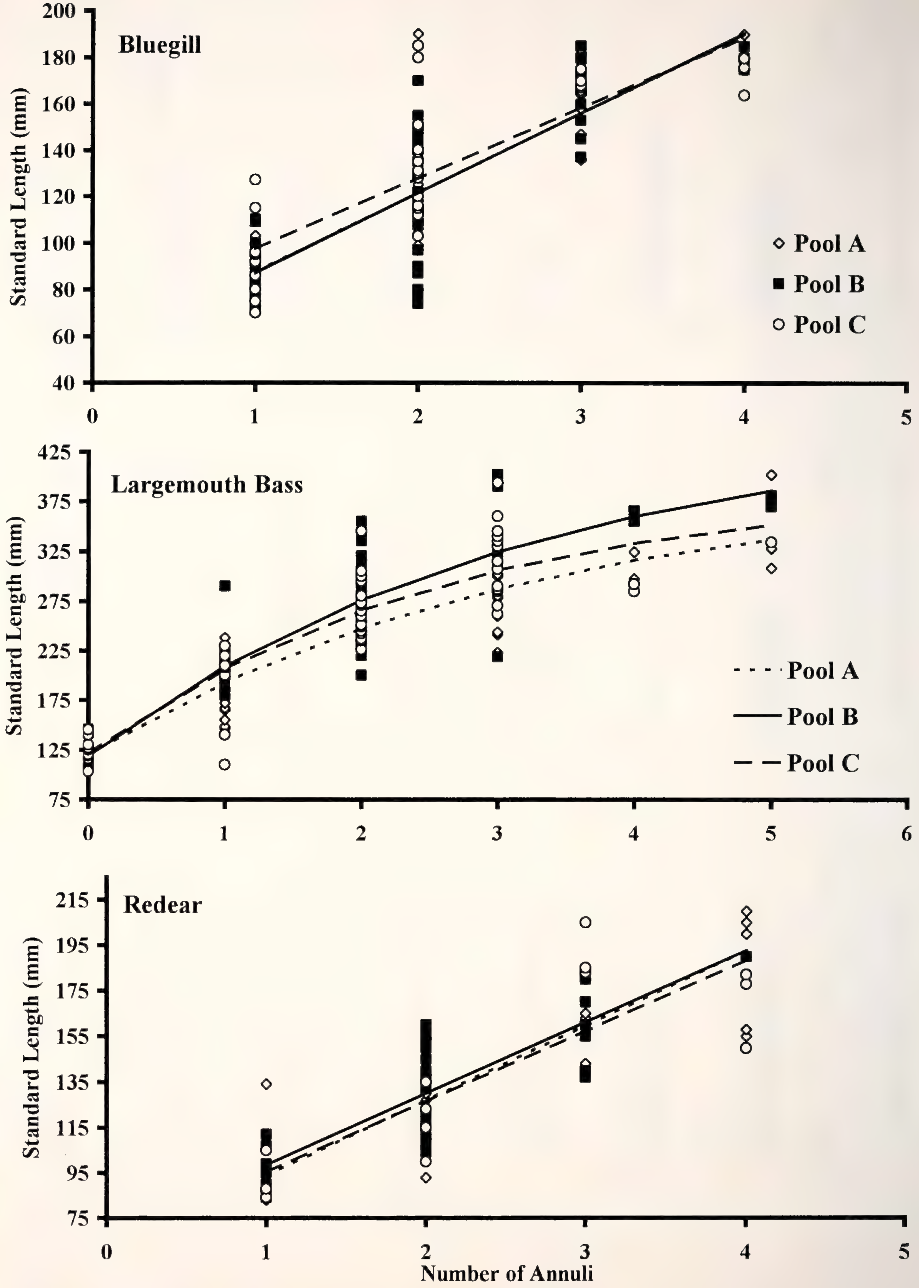


FIG. 5. Functional relationship of standard length (SL) on age (A) for bluegill, largemouth bass, and redear for Pools A, B, and C. Bluegill linear function for Pool A: SL = 34.34(A) + 52.96, $r^2 = 0.74$; Pool B: SL = 34.52(A) + 52.47, $r^2 = 0.63$; Pool C: SL = 30.51(A) + 66.84, $r^2 = 0.73$. Largemouth bass von Bertalanffy function for Pool A: $L_t = 395.1(1\text{-}e^{-0.313(t+1.152)})$, adjusted $r^2 = .85$; Pool B: $L_t = 456.5(1\text{-}e^{-0.313(t+0.963)})$, adjusted $r^2 = .82$; Pool C: $L_t = 391.9(1\text{-}e^{-0.383(t+0.961)})$, adjusted $r^2 = .83$. Redear linear function for Pool A: SL = 33.10(A) + 60.63, $r^2 = 0.80$; Pool B: SL = 31.32(A) + 67.39, $r^2 = 0.73$; Pool C: SL = 31.05(A) + 64.43, $r^2 = 0.73$.

ships of W on SL for largemouth bass and redear did not differ significantly among pools (slope test (largemouth bass $F_{2,197} = 0.20$, $p>0.8$; redear $F_{2,75} = 0.34$, $p > 0.7$); intercept test (largemouth bass $F_{2,201} = 1.47$, $p > 0.2$; redear $F_{2,79} = 0.08$, $p > 0.9$)) (Table 1). However, the slopes of the log-linear relationships of W on SL for bluegill were significantly different ($F_{2,152} = 13.56$, $p > 0.0001$) among the three pools. Bluegill growth exponent *b* was not significantly different between control pools (planned comparison $F_{1,99} < 0.01$, $p > 0.9$); however, growth exponent *b* was significantly greater for bluegill collected in the enhanced pool than bluegill collected from control pools (Table 1, planned comparison $F_{1,152} = 27.10$, $p = 0.0001$). This difference appears primarily due to small bluegill from the enhanced pool having a lower weight than similar sized bluegill collected from the control pools (FIG. 5).

Largemouth bass collected in the enhanced pool grew at a significantly faster rate and reached a larger maximum size than largemouth bass collected in the control pools. Linear equations were used to describe the relationship between SL and age for bluegill, largemouth bass and redear. This relationship did not differ significantly among pools for either bluegill or redear (Fig. 5; slope test (bluegill $F_{2,144} = 0.53$, $p > 0.5$; redear $F_{2,71} = 0.10$, $p > 0.9$); intercept test (bluegill $F_{2,148} = 1.19$, $p > 0.3$; redear $F_{2,75} = 0.29$, $p > 0.7$)). However, largemouth bass linear relationships for SL at age were significantly different among pools (slope test ($F_{2,194} = 2.83$, $p > 0.05$), intercept test ($F_{2,198} = 9.92$, $p = 0.0001$)). Comparisons of mean largemouth bass lengths, after adjusting for a common mean age, reveal significantly larger (longer) largemouth bass in the enhanced pool (mean ± standard error = 250.9 ± 4.06) than in the control pools A (224.4 ± 4.27) and C (240.1 ± 4.45) (planned comparison $F_{1,194} = 13.04$, $p = 0.0004$). Consequently, at any given age largemouth bass collected in the enhanced pool would be expected to be larger than largemouth bass collected in the control pools; and largemouth bass collected in Pool C expected to be longer than those collected in Pool A (planned comparison $F_{1,123} = 6.35$, $p < 0.02$).

The von Bertalanffy growth function produced higher adjusted r^2 values for estimates of largemouth bass growth than the simple linear model (0.82 and 0.77 respectively) and is plotted for largemouth bass in Fig. 5. Growth rates for both bluegill and redear were fit equally with either a linear or von Bertalanffy model. Furthermore, the von Bertalanffy growth function estimated extremely high values of L_∞ (maximum size) for bluegill and redear that logically have no biological significance (Zivkov et al., 1999).

DISCUSSION—We believe our analyses indicate the growth exponent *b* and growth rates of fishes show promise as indicators of ecosystem enhancement effects and therefore warrant further research as tools for evaluation of ecosystem enhancement and restoration. The growth exponent *b* was significantly different (steeper slope) for enhanced-pool bluegill than bluegill collected in the control pools, with no significant difference between bluegill collected in the control pools. Largemouth bass grew significantly faster and had a greater maximum size (growth asymptote, L_∞), on average, in the enhanced pool than in the two control pools.

Juvenile bluegill (log SL $\leq$ 1.9; ~80 mm) collected in the enhanced pool weighed less than similar sized bluegill collected in the control pools. Possible causes of observed variation in growth exponent b and growth rates in fishes include variations in temperature, food availability, habitat quality, density-dependent interactions and alterations in life-history characteristics (Mittelbach, 1981; Osenberg et al., 1988; Adams, 1990a; 1990b; Fox, 1994; Jobling, 1995; Reznick et al., 1996). Monthly surface water temperatures collected from Pools A, B and C during the period 1984–1997 do not appear to differ among the pools (SFWMD, 2000). We believe the most likely explanation for variation in enhanced-pool bluegill growth exponent b is that ecosystem enhancement efforts directly (decreased prey availability) or indirectly (increased competition or sub-optimal habitat use due to increased risk of predation) decreased food availability for small size classes of bluegill. Ecosystem enhancements have shifted three remnant river channels within the enhanced pool from lentic to more lotic conditions (see Pool B Ecosystem Enhancement section), and reduced open-water zooplankton abundances within the ehncanced pool (Joseph W. Koebel, Jr., 1999). Because larval and juvenile bluegill depend on zooplankton for food (Garvey and Stein, 1998), this may have resulted in decreased weight at length for small-bodied, enhanced-pool bluegill.

Another factor that may account for differences in growth exponent b of enhanced-pool bluegill is increased competition for prey. Wullschleger and co-workers (1990) indicated the Demonstration Project resulted in increased production and recruitment of bluegill, redear, spotted sunfish (*Lepomis punctatus*) and warmouth (*Lepomis gulosus*) due to increased spatial and temporal levels of floodplain inundation. Consequently, juvenile bluegill from the enhanced pool may weigh less than similar sized bluegill from the control pools because of increased interspecific and/or intraspecific competition at small size classes. In a study of bluegill growth in nine Michigan lakes, Osenberg and co-workers (1988) found growth of small bluegill exhibited negative density-dependence; however the growth rate for large bluegill had no such negative density-dependence. Similarly, our data indicate that the growth exponent b of large bluegill from the enhanced pool were not different from similar sized bluegill collected in the control pools. These size biased differences may be alleviated through prey switching and/or decreases in competition as the bluegill grow, because as bluegill grow their diet shifts (Stuber et al., 1982a) to include aquatic and terrestrial insects (potentially produced in the littoral zone or on the floodplain) allowing their growth exponent b in the enhanced pool to increase to levels observed in the control pools. Another possible explanation is that enhanced-pool bluegill experience an increased risk of predation (due to higher densities of largemouth bass in the enhanced pool, Furse et al., 1996) that may have caused those fish <100 mm to use sub-optimal habitats (Mittelbach, 1981); larger enhanced-pool bluegill would have been liberated to feed in more optimal habitats.

We analyzed growth rates using estimated linear relationships between SL and age. For bluegill and redear this was a reasonable method because these fish were limited to ages 1 through 4. This limitation is based on the recommendation to limit growth analyses to ages common to both populations (Zivkov et al., 1999). The von Bertalanffy growth function produced unrealistic estimates of the maximum size (asymptotic length, L_∞) for bluegill and redear (results not presented). These results are probably due to the lack of very young and old fish in our analysis. The von Bertalanffy model yielded better estimates for largemouth bass growth rates presumably because fish from ages 0 through 5 were included.

Although we observed considerable inter-individual variation in growth rates, largemouth bass grew significantly faster and reached a greater maximum size, on average, in the enhanced pool than in the two control pools (FIG. 5). Neither bluegill nor redear grew at significantly different rates among pools. The overlap of length distributions of various ages for each species (Fig. 5) has been found previously (Gerking, 1962; Maceina, 1992), and may be due to a number of factors including gender-specific growth rates, size-related prey availability, protracted spawning season, and Lee's Phenomenon (increased survivorship of slow growing cohort members; Ricker, 1975).

A possible explanation for the larger largemouth bass in the enhanced pool is that ecosystem enhancements resulted in increased food availability and food quality within the enhanced pool. Wullschleger and co-workers (1990) found increased production and recruitment of bluegill in the enhanced pool, and Toth (1990) found an increased abundance of two small-bodied fishes (*Gambusia holbrooki* and *Heterandria formosa*) as floodplain habitats were inundated due to Pool B ecosystem enhancements. Furthermore, increased floodplain forage production was found to be exported to the river channel during falling water periods (Toth, 1990). Largemouth bass collected in the control pools consumed a significantly larger proportion of grass shrimp (*Palaemonetes paludosus*) than largemouth bass collected in the enhanced pool, which fed more heavily on fishes (Frank Jordan and DAA, unpublished data). Furthermore, Jordan and Arrington found fewer empty stomachs, more prey items per individual, and greater diversity of prey in piscivores collected from the enhanced pool. Although largemouth bass growth rates differed between the control pools, both Pool A and Pool C growth rates were below the enhanced pool (Fig. 5). Two potential explanations for the observed variation between the control pools are: (1) natural geographic and environmental variation between the pools, and (2) possible downstream effects from the upstream Pool B enhancements. Currently, we lack conclusive data that addresses these differences.

Changes in the growth exponent *b,* condition factor and growth rates of fishes have been used to infer aquatic habitat quality (Olson et al., 1998; Khan, 1999; Luecke et al., 1999; Ogutu-Ohwayo, 1999; Mills et al., 2000). However, plasticity in life-histories allow fishes to vary the allocation of surplus energy (Roff, 1984; Reznick et al., 1990, 1996; Hutchings, 1993), such that fishes experiencing increased food availability may reproduce at an earlier age. Consequently, an alternative explanation for the observed disparity in growth rates and maximum size of largemouth bass among the pools could be that control-pool largemouth bass experienced increased food availability and reproduced at an earlier age, which caused them to be smaller and grow slower than enhanced-pool largemouth bass. However, stomach content data from the fish we examined indicate that enhanced-pool largemouth bass consume higher quality food items than control-pool largemouth bass (Frank Jordan and DAA, unpublished data). Although we did not examine age at maturity or investment in reproduction, alterations of life history characteristics do not appear to account for observed differences in growth rate and maximum size between enhanced-pool and control-pool largemouth bass.

One critical factor that regulates growth rates of fishes, regardless of the amount of food present, is the amount of dissolved oxygen in the water column (Stewart et al., 1967; Brett and Groves, 1979; Cuenco et al., 1985; Neill and Bryan, 1991; Buentello et al., 2000). Consequently, we anticipated growth rates of these three centrarchids in the enhanced pool might have been constrained because persistent low dissolved oxygen levels continue to impair the enhanced Pool B ecosystem (Fig. 3; Bull et al., 1991, 1994; Toth, 1993). A recent radio tracking study of largemouth bass found mortality of largemouth bass tagged with radio transmitters during the summer, presumably due to extremely low dissolved oxygen concentrations (Bull et al., 1994). An additional factor that may have influenced our results is that the C-38 canal provides suitable, but not optimal, habitat for centrarchids (Stuber et al., 1982a; 1982b; Twomey et al., 1984), which are often classified as tolerant of a broad suite of conditions (Whittier and Hughes, 1998). Based on criteria in the habitat suitability models for these three species, the major negative impact from the channelized ecosystem would be low dissolved oxygen during the summer (Stuber et al., 1982a; 1982b; Twomey et al., 1984), which remains a problem within the enhanced pool (Fig. 3).

Previously, Karr (1981) and Karr and co-workers (1986) incorporated twelve measures of fish communities, including fish condition, in their index of biotic integrity (IBI) for aquatic habitats. Later, Karr (1991) indicated growth rates and the condition factor (K) for individual fish could be incorporated into the IBI. There is a long tradition of using fish condition as a measure of individual and population health (Anderson and Neumann, 1996). Furthermore, the growth exponent *b* and growth rates of fishes have been found to be positively correlated with variations in habitat quality (Olson et al., 1998; Khan, 1999; Luecke et al., 1999; Mills et al., 2000). We, therefore, recommend further research on the use of the growth exponent *b* and growth rates of fishes in the evaluation of restoration projects, because they are quick and inexpensive metrics that may be used independently or incorporated with population and community-based measures. We also recommend future investigations evaluate age at maturity and relative allocation to reproduction (gonadosomatic index), because alterations in habitat quality may result in trade-offs among life-history characteristics (Hutchings, 1993; Reznick et al., 1996). Additionally, we recommend future investigators carefully select indicator species with narrower performance curves (i.e., less tolerant) than the three species we used in our analyses. By using species sensitive to critical ecosystem attributes (i.e., temperature, dissolved oxygen, food availability, spawning habitat), restoration evaluation programs can be designed to increase the likelihood of response detection.

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THE PRESENCE OF AN ASIAN LEECH, *BARBRONIA WEBERI,* IN A HOME AQUARIUM IN SOUTH FLORIDA (HIRUDINEA: SALIFIDAE)

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ABSTRACT: Barbronia weberi *(Blanchard, 1897), an Asian freshwater leech predaceous on invertebrates, is reported from Florida. This is the first record of this species in North America. Anatomical and distributional notes are given for the species.*

ON July 10, 1998, a Cape Coral (Lee County), Florida resident stopped by the Punta Gorda Branch Office of the Florida Department of Environmental Protection with two live specimens of "many mysterious worms" that had "suddenly appeared" in her home aquarium. She was concerned they might be some kind of parasite. On cursory inspection, Albert (Ford) Walton Jr. identified the specimens as a leech, most likely the commonly encountered *Mooreobdella tetragon* Sawyer and Shelley, 1976. Bob Rutter examined the specimens under a stereomicroscope several days later, curious to see if they might be the less common *Mooreobdella microstoma* (Moore, 1901). He discerned what appeared to be two additional gonopores. Thinking he had an aberrant *Mooreobdella,* he forwarded the specimens to Dr. Donald J. Klemm, who had published an identification guide for the leeches of Florida (Klemm, 1995). Klemm identified the leech as *Barbronia weberi* (Blanchard, 1897) based on illustrations and text presented by Sawyer (1986) and Nesemann (1995).

Preserved (80% ethanol) specimens of *Barbronia weberi* (Family Salifidae) are superficially very similar in appearance to preserved specimens of *Mooreobdella tetragon* and *M. microstoma* (Family Erpobdellidae), with no apparent difference in color, size, shape or ornamentation. Under magnification, however, the arrangement of the six eyes (three pairs) and the external two accessory copulatory pits on the ventral surface, anterior and posterior to the gonopores at segments X/XI and XIII/XIV, are diagnostic features for *B. weberi.* The presence of three pairs of retractile stylets, sometimes difficult to discern, on the anterior ends of each pharyngeal ridge also differentiates the Salifidae from the Erpobdellidae (Nesemann, 1995).

Sawyer (1986) discussed the passive and accidental introduction of leeches or their cocoons by the importation of aquatic plants, and documented the introduction of *Barbronia weberi* into Great Britain. The taxon has a poorly defined zoogeographic distribution in the Palaearctic Region and New Zealand. Distributional records of *B. weberi* from Germany (Potel et al., 1998), China (Yang et al., 1997) and the Seychelles (Gerlach, 1997) were also reported. Bennike (1943) reported the introduction into Denmark of another leech species, *Helobdella triserialis* (E. Blanchard, 1849), whose only known distribution was in North and South America. Other possible means of passive dispersal of certain leech species discussed and reported by Davies and co-workers (1982) and Sawyer (1986) were by normal hosts, animals (such as birds), water currents, and humans.

To date there has been no known record of the collection of *Barbronia weberi* from a natural freshwater habitat in Florida, but its presence in a south Florida aquarium bodes that perhaps someday there will. Two Asian aquatic insects are already established in south Florida, the dragonfly *Crocothemis servilia* (Drury) (Paulson, 1978; Daigle and Rutter, 1984) and the corixid *Synaptonecta issa* (Distant) (Polhemus and Rutter, 1997). Paulson (1978) did not speculate on the mechanism of introduction of the former, but the aquarium plant trade was implicated in the presence of the latter.

For future reference and examination, the two specimens were deposited in the U.S. National Museum of Natural History (USNM 187083), Division of Worms, Smithsonian Institution, Washington, D.C.

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MOSQUITO (DIPTERA: CULICIDAE) AND BITING MIDGE (DIPTERA: CERATOPOGONIDAE) COLLECTIONS IN FLORIDA KEYS STATE PARKS

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ABSTRACT: *Mosquitoes and biting midges were collected from Florida State Parks in Monroe County during 1999 and 2000 with the aid of carbon dioxide-baited light traps.* Ochlerotatus taeniorhynchus *was the mosquito species most commonly collected, comprising 94.6% of specimens in 1999 and 83% in 2000. Other mosquitoes collected were* Aedes aegypti, Anopheles atropos, An. crucians *complex,* Culex bahamensis, Cx. nigripalpus, Cx. quinquefasciatus, Deinocerites cancer, Oc. infirmatus, Oc. sollicitans, Oc. triseriatus, *and* Psorophora johnstonii. *The only biting midges collected were* Culicoides arboricola *and* C. furens.

THE MOSQUITO (Diptera: Culicidae) fauna of the Florida Keys was last surveyed in the 1940s (Pritchard et al., 1949), although individual species have been studied in the years since then. The biting midge (Diptera: Ceratopogonidae) or "no-see-um" fauna of the Florida Keys is not well studied (Blanton and Wirth, 1979). During the past 50 years there has been significant development of the islands, resulting in increased human population and destruction of natural habitat areas. Because very little data are available regarding the mosquito and no-see-um fauna of this area, a survey was begun to gather information on the current geographic and temporal distribution of these insects, and to verify older records. Collections were made in State Parks in the Florida Keys to supplement collections in other areas of the Keys. This paper reports collections made under permits 5–99–10 and 5–00–15 issued by the Florida Department of Environmental Protection Division of Recreation and Parks.

METHODS—Dry Ice-baited traps were placed once per month from April to September 1999 and 2000 in the following Florida State Parks: John Pennekamp Coral Reef State Park (SP), Key Largo; Long Key SP, Long Key; Curry Hammock SP, Long Point Key; Bahia Honda SP, Bahia Honda Key; and Fort Zachary Taylor State Historic Site (SHS), Key West. Windley Key Fossil Reef State Geological Site (FRSGS), Windley Key, was added in 2000. Traps were hung in areas that were not accessible by the general public and trap sites were approved by Park Managers. In the John Pennekamp SP, Long Key SP, and Fort Taylor SHS, the traps were placed near the shop buildings. At Bahia Honda SP the trap was hung near the sewage treatment plant, and at Curry Hammock SP and Windley Key FRSGS the traps were suspended from a tree located in an area with restricted access. Traps were hung before sunset and retrieved the following morning. Specimens were returned to the laboratory, frozen, and identified to species

(Darsie and Morris, 1998; Wirth and Blanton, 1974; Blanton and Wirth, 1979). Following new systematic studies, many species formerly placed in genus *Aedes* now are placed in genus *Ochlerotatus* (Reinert, 2000). Mosquito generic abbreviations are those of Reinert (1975, 2000). Due to the difficulty of separating adult females of *Anopheles bradleyi* King, *An. crucians* Wiedemann, and *An. georgianus* King, these are reported as *An. crucians* complex. Voucher specimens have been placed in the Florida State Collection of Arthropods and the Florida Keys Mosquito Control District mosquito collection.

RESULTS AND DISCUSSION—A total of 13,834 mosquitoes was collected in 1999, and 17,597 mosquitoes were collected in 2000. The Black Saltmarsh Mosquito, *Ochlerotatus taeniorhynchus* (Wiedemann), was the species most commonly collected, comprising 16,641 or 94.6% of mosquitoes captured in 1999 and 11,484 or 83% of mosquitoes captured in 2000. Other species encountered were the Yellow Fever Mosquito, *Aedes aegypti* (Linnaeus); *Anopheles atropos* Dyar and Knab; *An. crucians* complex; the Bahamian Culex, *Culex bahamensis* Dyar and Knab; *Cx. nigripalpus* Theobald; the Southern House Mosquito, *Cx. quinquefasciatus* Say; the Crab Hole Mosquito, *Deinocerites cancer* Theobald; *Oc. infirmatus* (Dyar and Knab); the Golden Saltmarsh Mosquito, *Oc. sollicitans* (Walker); *Oc. triseriatus* (Say); and the Antillean Psorophora, *Psorophora johnstonii* (Grabham). Relative abundance of mosquito species in trap samples is presented in Table 1.

No-see-um collections in 1999 totaled 6,239, all but three of which were the Little Gray Saltmarsh Punky, *Culicoides furens* (Poey). Three tree hole midges, *C. arboricola* Root and Hoffman, were collected at Ft. Taylor SHS. In 2000, no-see-um collections totaled 6,742. Two tree hole midges, *C. arboricola,* were collected at Ft. Taylor SHS. The rest (6,740) were *C. furens.* This species was collected from all parks in both years. The collections of *C. arboricola* from Key West represent a new distribution record, as this species previously had been known only as far south and west as Vaca Key.

It is interesting to compare collections made in 1999 and 2000. More mosquitoes in total were collected in 2000 than in 1999 (17,597 vs. 13,834) an increase of 3,763. More *Oc. taeniorhynchus* were collected in 2000 in every park except Ft. Taylor SHS, where numbers both years were so small that the difference probably is insignificant. No collections were made in Windley Key FRSGS in 1999, but *Oc. taeniorhynchus* was the species collected in largest numbers in 2000. *Anopheles atropos* was collected from more parks in 2000 than in 1999, whereas *Cx. bahamensis* was collected from more parks in 1999 than in 2000. *Anopheles crucians* complex was not collected in 1999, but was collected in 2000. *Aedes infirmatus* and *Ps. johnstonii* were collected in 1999 but not in 2000. All mosquito and biting midge collections from Long Point Key appear to be new locality records.

At least 43 mosquito species have been collected in Monroe County, Florida (Darsie and Morris, 1998). Only 12 species were collected in the present study. Eight species of no-see-ums are known from the Florida Keys (Blanton and Wirth, 1979), yet only two species were detected during this

TABLE 1. Mosquito Collections from Florida State Parks, Monroe County, Florida, 1999–2000.

	Bahia Honda		Curry Hammock		Ft. Taylor		John Pennekamp		Long Key		Windley Key
Species	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	2000
Aedes aegypti	0	0	0	0	1	5	21	11	1	1	0
Anopheles atropos	19	16	68	3	0	0	0	0	0	4	8
An. crucians complex	0	1	0	0	0	0	0	0	0	0	0
Culex bahamensis	711	521	134	2	0	1	0	0	32	0	0
Cx. nigripalpus	0	0	2	12	0	0	5	7	65	7	6
Cx. quinquefasciatus	0	0	0	0	6	4	0	0	0	2	1
Deinocerites cancer	1,078	175	82	19	0	0	3	13	99	89	45
Ochlerotatus infirmatus	0	0	0	0	0	0	0	0	8	0	0
Oc. sollicitans	0	0	4	0	0	0	0	0	0	0	0
Oc. taeniorhynchus	7,517	9,242	1,199	2,583	35	5	911	1,634	1,802	2,808	360
Oc. triseriatus	0	0	0	0	0	0	3	5	0	0	0
Psorophora johnstonii	0	0	0	0	0	0	0	0	8	0	0
Annual totals	9,325	9,955	1,489	2,619	42	15	943	1,670	2,015	2,911	420

study. One reason for these differences is some mosquito species known to occur in the county are not often collected in light traps. Only one trap was placed in each park, and some mosquito and no-see-um species occupy habitats that were not sampled during this study. The parks studied are located on islands that are very different from each other. Over 100 miles separate Ft. Taylor SHS and John Pennekamp SP; differences in vegetation, proximity to the mainland, and development outside the parks may have affected collections.

One question not yet answered is the effect of mosquito control operations on the distribution and abundance of mosquito species in the Florida Keys. Regrettably, prior to 1998 no systematic mosquito surveillance was conducted on these islands. It is known, however, that mosquito control operations cause temporary, local reductions of mosquito populations. These populations are quickly replaced by breeding of survivors and by migration from untreated areas (Provost, 1952). Recent surveys have revealed that several uncommon mosquito species occur in areas where mosquito control practices regularly take place (Hribar, 1999, 2001). Further studies comparing treated and untreated areas within the Florida Keys should document any effects on mosquito populations.

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Oceanographic Sciences

TIDES OF BISCAYNE BAY, CARD SOUND, BARNES SOUND, AND MANATEE BAY, FLORIDA

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ABSTRACT: *Water level data from a 1997–98 field study conducted in the coastal bays at the southeast tip of the Florida peninsula are combined with water level records from earlier field studies to characterize semidiurnal and diurnal period tidal constituents in Biscayne Bay, Card Sound, Little Card Sound, Barnes Sound and Manatee Bay. Results indicate uniform amplitudes and rapid filling and draining through much of the northern part of the study area. Semidiurnal* M_2 *constituent amplitudes are approximately 30 cm;* N_2 *and* S_2 *constituent amplitudes are approximately 8 and 5 cm, respectively. The diurnal* K_1 *and* O_1 *constituents have amplitudes of about 3 cm. In the southern part of the study area, a series of shallow banks reduces the amplitudes of all tidal constituents. In Barnes Sound and Manatee Bay,* M_2 *amplitudes are about 5 cm, while all other constituents have amplitudes on the order of 1 cm. Calculations of bay volume relative to mean sea level indicate that 85% of all flood tides and 87% of all ebb tides transport from 200 to 350* $\times 10^6$ m^3 *of water into or out of the Biscayne Bay System. The* M_2, S_2, N_2, K_1 *and* O_1 *tidal constituents have amplitudes of 134.0, 19.3, 26.2, 17.2 and 13.6* $\times 10^6$ m^3*, respectively. Under neap and spring tide conditions, flood and ebb intertidal volumes can be as little as 164* $\times 10^6$ *or as much as 394* $\times 10^6$ m^3*. Acoustic Doppler profiler data from two locations in central and southern Biscayne Bay indicate a south-southwestward tide-induced residual transport from Biscayne Bay into Card Sound.*

BISCAYNE Bay, Card Sound, Little Card Sound, Barnes Sound and Manatee Bay, referred to here as the Biscayne Bay System, lie at the southeastern tip of the Florida Peninsula (Fig. 1). The combined surface area of the bays between 25° 55.7′(North Miami Beach) and 25° 11.7′N (Jewfish Creek) is approximately 703 km^2. A series of banks and causeways defines the individual basins, and these topographic features may have a significant effect on the exchange of water between basins. Within Biscayne Bay, Featherbed Bank separates a slightly larger northern basin from a smaller southern basin. Cutter Bank separates Biscayne Bay from Card Sound, and Card Bank separates Card Sound from Little Card Sound. A causeway, broken by the Intracoastal Waterway, separates Little Card Sound from Barnes Sound. Water depth is highly variable. Channels in northern Biscayne Bay are dredged to depths of 10 m to accommodate cruise ships, while large parts of southern Biscayne Bay, Card Sound, Little Card Sound, Barnes Sound and Manatee

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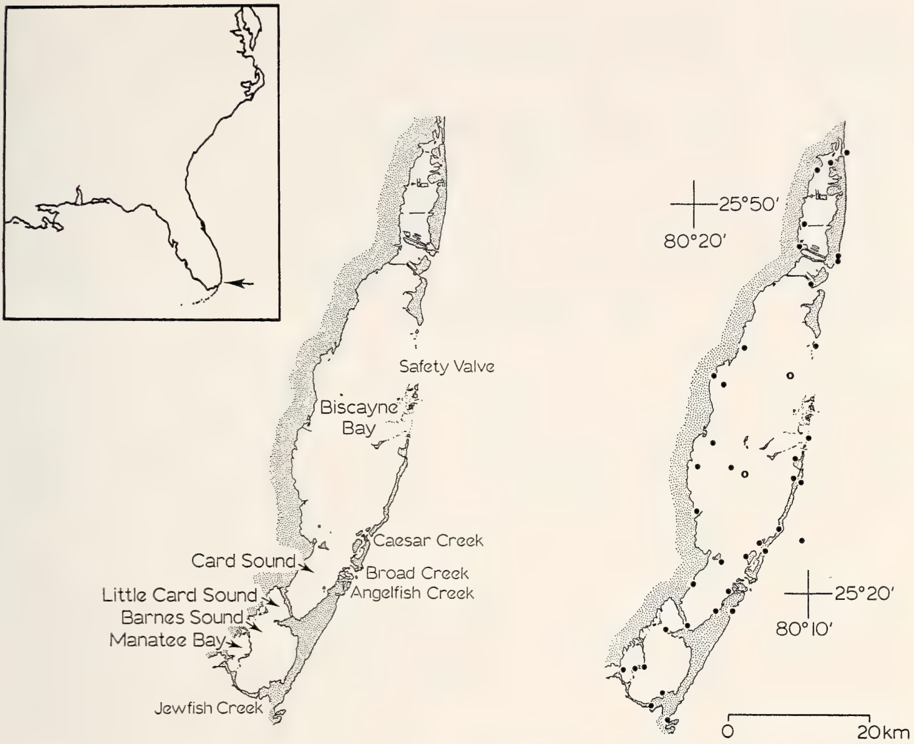

FIG. 1. Maps showing (left) locations of Biscayne Bay, Card Sound, Little Card Sound, Barnes Sound and Manatee Bay; and (right) locations of water level recorders used for calculating co-amplitude and co-phase charts, and for calculations of bay volume. Closed circles show locations of water level recorders. Open circles west of the Safety Valve and in southern Biscayne Bay show locations of acoustic Doppler profilers. The solid square on the western shore of southern Biscayne Bay indicates the location of the weather station. Insert shows the study area at the southern end of the Florida Peninsula.

Bay are less than 1 m deep. The Intracoastal Waterway, running north-south through the bays, is dredged to a depth of 2.1 m.

Growing population pressures and a concern for water quality have prompted a series of studies over the past three decades to characterize flow patterns and especially flushing rates in the Biscayne Bay System (Lee and Rooth, 1973; 1976). Studies have emphasized computer modeling for the most part (Miller, 1984; Wang and van de Kreeke, 1986; Wang et al., 1999), and the observational data base needed to characterize tidal conditions is restricted largely to that needed for model validation (see Taylor, 1971; Swakon and Wang, 1977; Wang and van de Kreeke, 1986). For the most part, tidal ranges are presented without regard to individual constituents, and phase angles are referenced to a primary coastal station.

Extensive field studies were conducted by the National Ocean Service (NOS) in the early 1970s. Numerous study sites were maintained along both the eastern and western shores of the Biscayne Bay System for time periods ranging from one 29-day synodic month to one year. Harmonic analysis of these water level records provided the harmonic constants needed for tidal predictions for the Miami Harbor entrance at Government Cut, and for corrections for other locations within Biscayne Bay and Card Sound. More recent field studies have improved station density and contributed bottom pressure records from several locations in the interior of the bays. Data from a one-year study by the Army Corps of Engineers Waterways Experiment Station (WES) and National Park Service (Pratt, 1999) are an important supplement to the earlier data collected from shore-based stations.

The purpose of this paper is to combine results of earlier and more recent studies into a data base of harmonic constants suitable for describing tidal conditions within the Biscayne Bay System and tidal exchanges between the bays and adjacent inner shelf waters. Results of this study provide an improved picture of tides in the Biscayne Bay System and a more complete data base for validating tidal transport and flushing models.

Data Collection—Harmonic constants (amplitudes and local phase angles) calculated from historical NOS water level data are available from 23 locations throughout the Biscayne Bay System (Lyles, 1999). Seventeen of the records are one synodic month long, and six are one year long. Twenty of the 23 NOS records were obtained from studies conducted between 1970 and 1975. Combining harmonic constants from earlier and more recent studies assumes that harmonic constants have not changed in the past 30 years. In northern Biscayne Bay, however, amplitudes may have increased somewhat as a result of dredging activities. The NOS water level records were collected with Stevens tide gauges which use a float and counterweight to follow the rise and fall of the water surface. Comparisons of tide staff and chart values in studies using the same recording instrumentation (Smith, 1987) suggest that the accuracy of the hourly values is ±0.5 cm, and the precision of the readings is 0.3 cm.

The WES field study (Pratt, 1999) produced water level data from 12 locations using YSI/Endeco Model 6000 pressure recorders. Hourly bottom pressure readings have an accuracy of 1.8 cm. For the purpose of characterizing the rise and fall of the tide, the ability of a recorder to sense the height of the overlying water column is of less importance than its ability to resolve hour-by-hour changes in water level. The resolution of the pressure recorders provides water levels to within ±0.03 cm, according to instrument specifications. The Model 6000 is not vented to the atmosphere, and it interprets changes in air pressure as changes in water depth. This is of significance in a tide study only insofar as surface air pressure changes associated with atmospheric tides can perturb the water pressure changes associated with oceanic tides. The WES field study included a weather station on the western side of Biscayne Bay (Fig. 1). Air pressure was recorded hourly to the nearest millimeter of mercury for a 355-day period from July 18, 1997 to July 7, 1998.

Water level records were available also from a South Florida Water Management District study at Thursday Point on the southeast shore of Barnes Sound, and from Harbor Branch studies in Jewfish Creek and in shelf waters northeast of the mouth of Caesar Creek. Using data from all sources, harmonic constants are available from 38 locations for constructing co-amplitude and co-phase charts and from 33 locations for calculating intertidal volumes.

The WES field study included acoustic Doppler profiler (ADP) data from five locations, two of which (shown by the open circles in the right-hand map of Fig. 1) were well positioned for characterizing tidal transport along the axis of Biscayne Bay. The ADP recorded currents in 4–10 layers, depending on mean water depth and tidal and nontidal changes in water level. The speed and direction accuracy of the ADP are ±1% of the indicated speed and ±1°, respectively (Slocum, 1999). Bottom pressures recorded by the ADP indicated water levels to the nearest 10 cm, and they were used for calculating surface-to-bottom transport but not for quantifying tidal harmonic constants.

METHODS—Water level records from the WES field study that were longer than 180 days were analyzed with a NOS least squares harmonic analysis computer program, "LSQHA," to quantify the harmonic constants of the principal tidal constituents (Schureman, 1958). The same program was used by the NOS to analyze the one-year records collected in their field studies. Excluding the long-period tidal constituents, only five constituents were found to have amplitudes greater than 1 cm throughout most of the Biscayne Bay System. The M_2, S_2, N_2, K_1 and O_1 constituents emerged as those having a significant impact on bay-shelf exchange calculations.

LSQHA was used also to quantify surface air pressure variations associated with atmospheric tides. Results indicated that only the S_2 atmospheric tide is large enough to influence significantly the S_2 ocean tidal constituent calculated from bottom pressure records. The S_2 atmospheric tide has an amplitude of 0.72 mm of mercury and a phase angle of 293°. This is 18 times larger than the amplitude of the O_1 atmospheric tide, the next largest. A pressure change of 0.72 mm of mercury is interpreted by the pressure recorder as a water level change of 0.96 cm. Harmonic constants calculated from the 12 WES bottom pressure records were corrected by vector-subtracting the S_2 atmospheric tide from the S_2 oceanic tide. The result is a closer approximation of the amplitude and phase angle that would have been obtained from a float-and-counterweight tide gauge. By adjusting harmonic constants through vector-subtraction, results of the LSQHA analyis of the air pressure record can be used to correct bottom pressure records collected from any nearby study site and for any time period. The importance of the correction varies inversely with the amplitude of the ocean tide. In Barnes Sound, where the effect was largest, the correction increased S_2 amplitudes by about 1 cm, and phase angles were advanced by about 30°.

The NOS analyzed synodic month water level records using their 29-day harmonic analysis computer program, "CURAN." CURAN analyzes five tidal constituents directly, the same five that emerged as principal tidal constituents in the Biscayne Bay System. To quantify the uncertainty in the harmonic constants obtained from a single 29-day harmonic analysis, the much longer WES time series were broken into 29-day segments and used for multiple CURAN analyses. For each of the five principal constituents, harmonic constants from multiple CURAN analyses were vector-averaged, and the root-mean-squared (RMS) deviation from the vector average was calculated for both amplitudes and phase angles. Results suggest that the RMS deviation of CURAN amplitudes, RMS_A, and phase angles, RMS_P, as a function of the LSQHA amplitude, A_L, decrease approximately exponentially according to

$$RMS_A = 0.4276 \text{ Exp}(-0.00347A_L), \quad \text{and} \tag{1}$$

$$RMS_P = 10.32 \text{ Exp}(-0.08314A_L). \tag{2}$$

Thus, for example, when an LSQHA amplitude calculated from a one-year time series is on the order of 1–2 cm, the RMS deviation of a CURAN amplitude calculated from a 29-day subset of the longer record will be approximately 0.5 cm. Similarly, the RMS deviation of the CURAN phase angle will be approximately 10°. Larger amplitude constituents are affected less. For the M_2 tidal constituent, with amplitudes near 30 cm in northern Biscayne Bay, the CURAN amplitudes and phase angles should be within ±0.4 cm and ±1°.

Harmonic constants from all 38 locations were used to construct co-amplitude and co-phase charts of the principal tidal constituents. Isopleths of amplitudes and phase angles in southern Biscayne Bay, Card Sound and Barnes Sound are the combined response to tidal waves entering directly from shelf waters and waves moving slowly southward into Barnes Sound. For the semidiurnal M_2, S_2 and N_2 constituents, co-phase charts were contoured at intervals of 30°, because a 30° phase difference represents an approximately one-hour difference in the time of high or low water. Co-phase charts for the diurnal K_1 and O_1 constituents were contoured at 15° intervals for the same reason.

Thirty-three of the 38 study sites were within the Biscayne Bay System. The surface areas they represent varied from 1.8 to 54.7 km². The tidal rise and fall in water level, η, at a station representing segment m, was estimated by summing the contributions of each of the five principal tidal constituents

$$\eta_m = \sum_{i=1}^{5} \eta_{m,i}. \tag{3}$$

The volume of water in segment m, V_m, relative to the tidal datum is obtained from the product of the predicted water level and the surface area of the segment, S_m. This assumes that the surface area of the segment does not vary with changes in water level. These products are then summed to obtain the hour-by-hour variation of the volume of the bay system relative to the datum,

$$V_T = \sum_{m=1}^{33} \eta_m S_m. \tag{4}$$

The intertidal volume associated with the flood or ebb phase of the tidal cycle is calculated from successive maximum and minimum bay volumes.

ADP data included east-west (u) and north-south (v) components of the current at each level. The local surface-to-bottom transport was calculated from

$$T_{E-W} = \sum_{i=1}^{n} u_i \Delta z, \qquad T_{N-S} = \sum_{i=1}^{n} v_i \Delta z, \tag{5}$$

where n is the time-varying number of layers in the profile. Tidal transport was isolated by using predicted tidal currents and a number of layers based on predicted water levels. Quarter-hourly transport was accumulated in time, and the resultant transport vector was used to quantify the magnitude and direction of the tide-induced residual flow.

RESULTS—*Co-amplitude and co-phase charts*–Amplitudes of the M_2 constituent are approximately 30 cm in coastal waters (Fig. 2), and amplitudes at the northern end of Biscayne Bay are similar to those found over the shelf. Amplitudes decrease only slightly in southern Biscayne Bay. The most rapid decrease occurs between southern Biscayne Bay and Card Sound. An additional decrease of 5 cm occurs between Little Card Sound and Barnes Sound.

The M_2 co-phase chart indicates phase lags of less than 30° throughout the northern half of Biscayne Bay. The 260 and 290° phase angles indicate that M_2 high and low tides in Biscayne Bay occur about an hour later south of Featherbed Bank than in the northern part of the bay. Within southern Biscayne Bay, M_2 waves moving southward from the Safety Valve interact with M_2 waves entering through Caesar Creek. Phase angles indicate that M_2 high and low tides in Barnes Sound occur approximately three hours later than in southern Biscayne Bay.

The co-amplitude chart for the N_2 constituent (Fig. 3) shows that amplitudes are on the order of 7–8 cm in shelf waters, and they are only slightly less throughout northern Biscayne Bay. Significant damping occurs within and south of Card Sound as a result of the shallow banks and causeway constrictions. Smallest amplitudes are on the order of 1 cm in Barnes Sound. The N_2 co-phase chart reveals a complex pattern, but most of the complexity

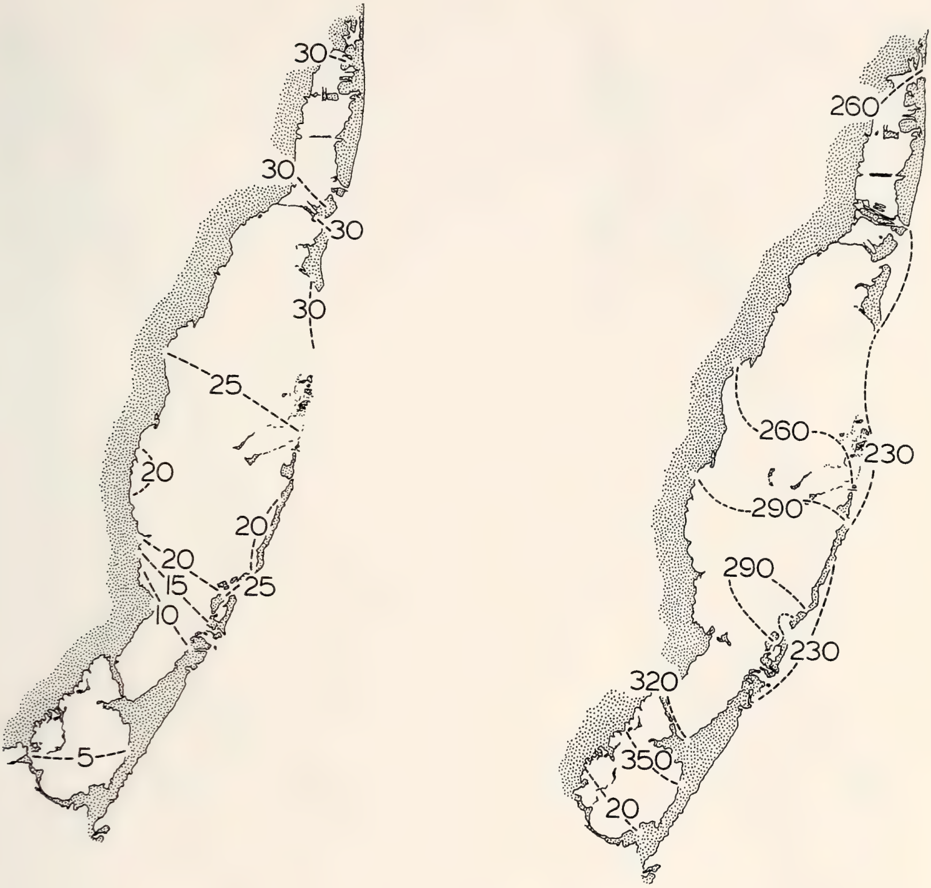

FIG. 2. (Left) Co-amplitude and (right) co-phase charts for the M_2 tidal constituent. Amplitudes are in cm; local phase angles are in degrees.

is restricted to the southern part of the study area. North of central Biscayne Bay, all phase angles are between 210 and 240°, indicating that high or low tide conditions are reached within a one-hour period of time. In southern Biscayne Bay, co-phase lines represent the local influence of N_2 waves moving in through Caesar Creek and perhaps Broad Creek. Phase angles increase by approximately 60° through Card Sound and Barnes Sound, indicating that high or low tides are delayed by an additional two hours relative to southern Biscayne Bay.

S_2 tidal amplitudes are somewhat smaller than N_2 amplitudes in northern Biscayne Bay, but amplitudes are similar in Card Sound and Barnes Sound (Fig. 4). In northern Biscayne Bay, phase angles at all study sites are within 30° of 270°, indicating a nearly in-phase relationship for the rise and fall of the tide. The local influence of direct exchanges with the inner shelf through Caesar Creek and Broad Creek appears in southern Biscayne Bay. Phase

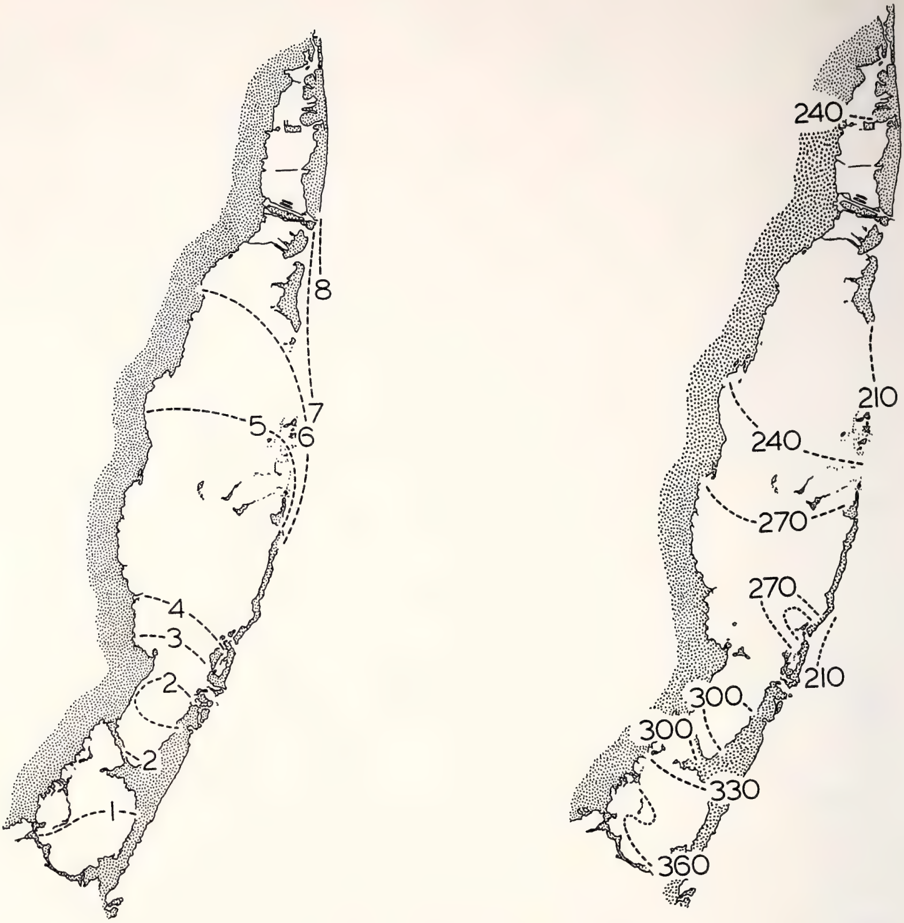

FIG. 3. Same as Fig. 2, except for the N_2 constituent.

angles increase southward by as much as 60°, indicating an approximately two-hour delay in times of high and low water at the southern end of the study area.

Diurnal tidal constituents produce simple co-amplitude charts, but co-phase charts are more complex than those representing semidiurnal tidal constituents. The small number of isopleths on the co-amplitude charts is due to the fact that diurnal constituents have low amplitudes, even in shelf waters. Amplitudes in northern Biscayne Bay are just over 3 cm for both the K_1 (Fig. 5) and O_1 (Fig. 6) constituents. Amplitudes decrease by only about 1 cm through Card Sound and Barnes Sound. The complexity in the co-phase charts is largely restricted to the southern part of the study area, where waves moving southward through Biscayne Bay interact with waves entering through Caesar Creek, Broad Creek and Angelfish Creek. Diurnal constituent phase angles are similar throughout northern Biscayne Bay. In

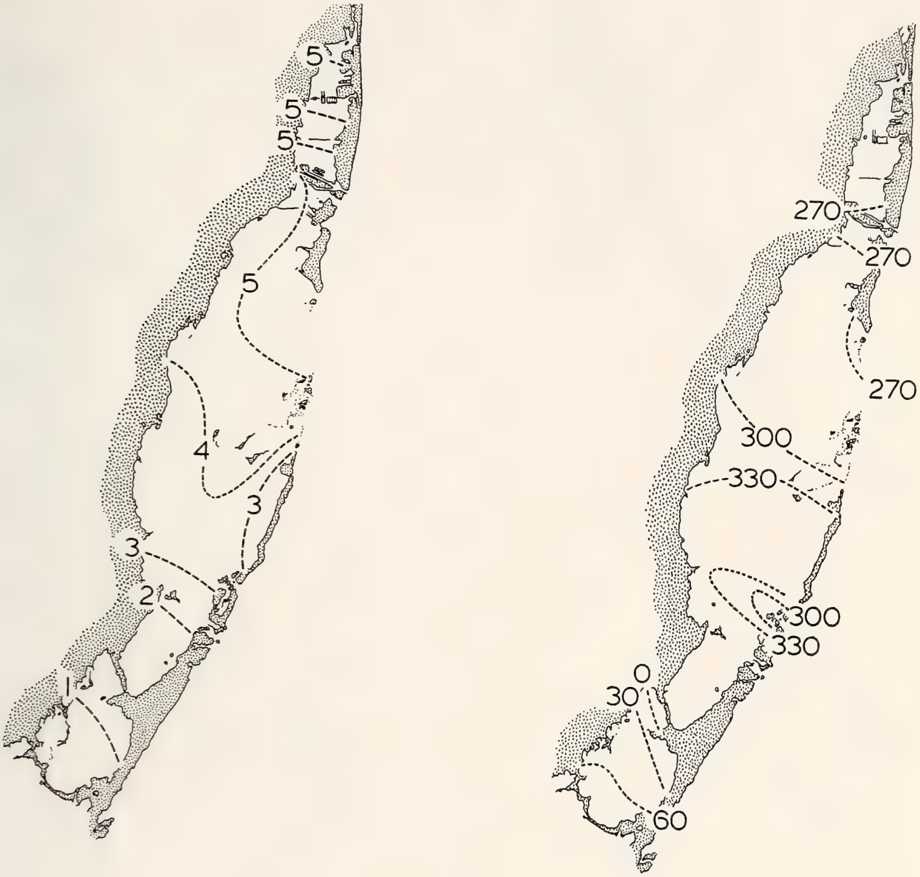

FIG. 4. Same as Fig. 2, except for the S_2 constituent.

the southern part of the bay differences of approximately 60° are equivalent to a time delay of about four hours.

Intertidal volumes—Harmonic constants for the five principal tidal constituents and from the 33 study sites within the Biscayne Bay System were used to make calculations of the hour-by-hour rise and fall in water level, and thus the tidal increase and decrease in volume. Histograms constructed from the 705 semidiurnal flood and ebb tide cycles that occurred during a one-year tidal prediction are approximately mirror images of each other (Fig. 7). The ebb tide histogram has a slightly higher peak, with the 275–300 × 10^6 m^3 bin accounting for 19.6% of the observations. The same bin in the flood tide histogram contains 18.7% of the observations. Both histograms are skewed slightly toward higher intertidal volumes. Flood and ebb tide volumes range between 164 and 394 × 10^6 m^3. Eighty-five percent of the flood intertidal volumes and 87% of the ebb intertidal volumes are between

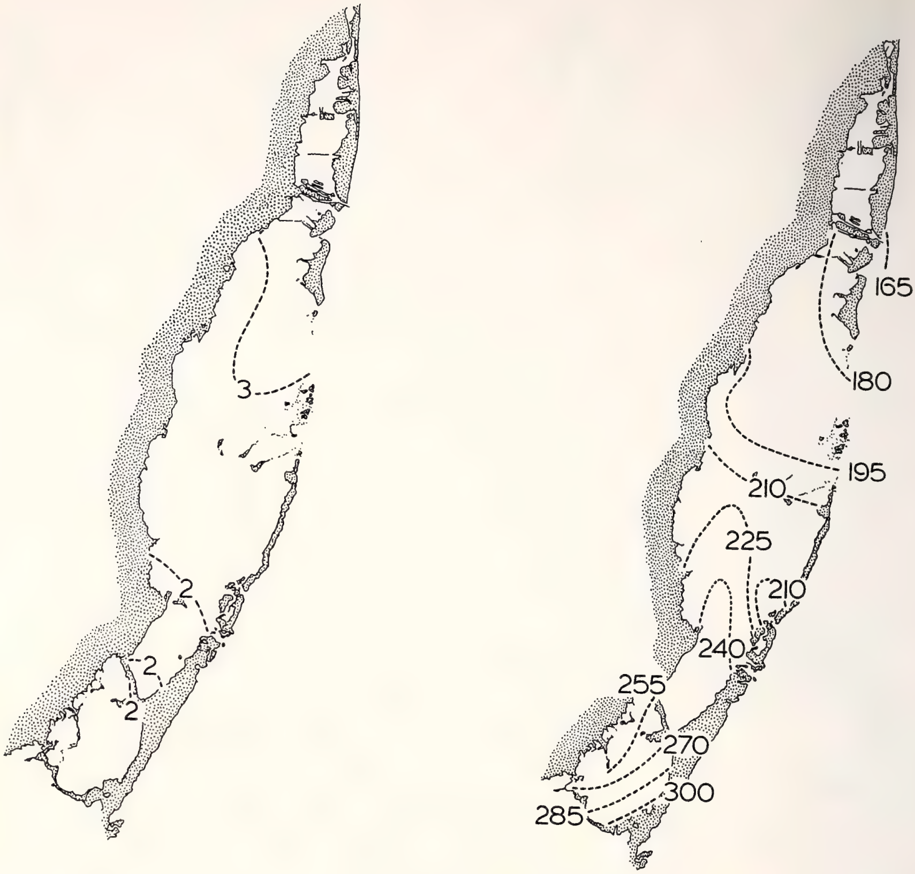

FIG. 5. Same as Fig. 2, except fot the K_1 constituent.

200 and 350 × 10^6 m^3. The spread of the histograms is a result of the interaction of individual tidal constituents (Table 1). As constituents cycle in and out of phase, they are alternately additive and subtractive, producing diurnal inequalities, and both fortnightly and monthly cycles.

Residual tidal transport—Acoustic Doppler profiler data are available from a study site in central Biscayne Bay, just west of the Safety Valve, and a second study site in southern Biscayne Bay. Combining the tidal rise and fall of water level with the ebb and flood of the current, one can quantify the local vertically-integrated residual transport. Results (not shown) indicate a south-southwestward transport at both locations. The tide-induced transport through central Biscayne Bay has a magnitude of 8.3×10^{-3} m^2 s^{-1} along a heading of 208°, and the transport past the station in southern Biscayne Bay has a magnitude of 7.8×10^{-3} m^2 s^{-1} with a heading of 207°. Results from both locations are consistent with the paradigm of a net inflow through

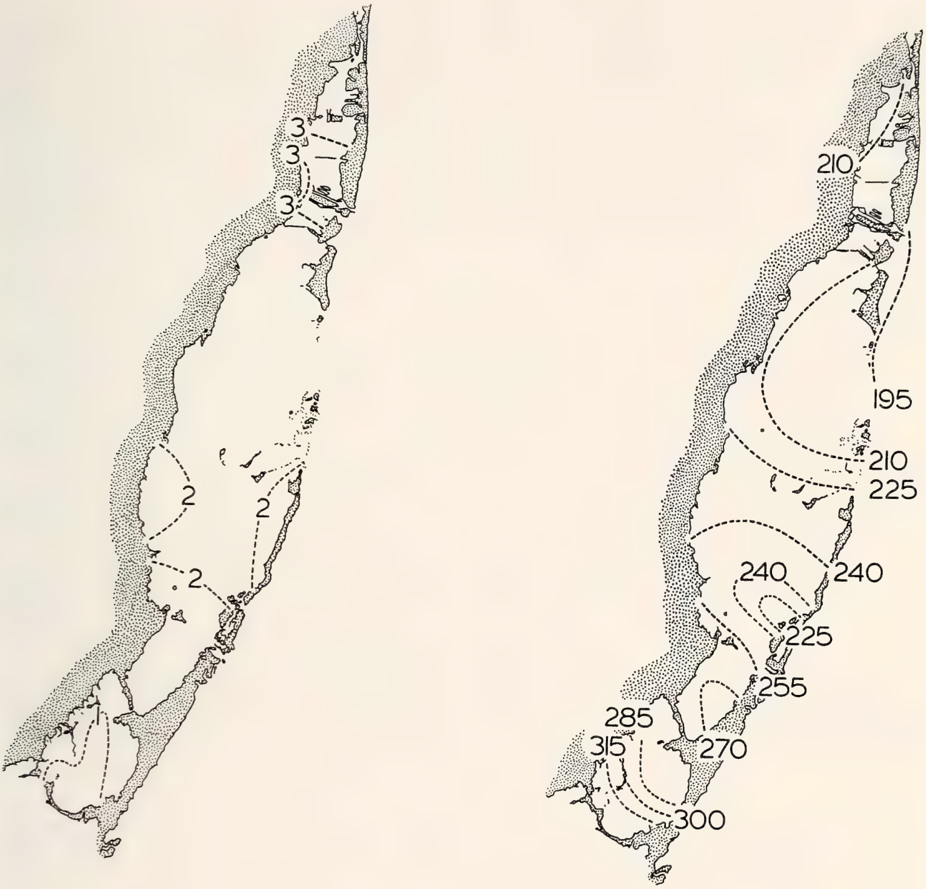

FIG. 6. Same as Fig. 2, except for the O_1 constituent.

the Safety Valve and a net outflow through the tidal channels in southern Biscayne Bay and Card Sound.

DISCUSSION—With the integration of harmonic constants from historical and recent water level records, the Biscayne Bay System can be characterized as microtidal, with amplitudes well below 1 m everywhere, and just a few centimeters in the more isolated, southern part of the study area. Co-amplitude charts show that the M_2 constituent is dominant, with amplitudes about five times greater than those of the N_2 and S_2 constituents throughout the study area. Amplitudes of the M_2 constituent are ten times those of the K_1 and O_1 constituents in Northern Biscayne Bay, but only 3–5 times as large in Barnes Sound. Co-phase charts indicate a nearly simultaneous rise and fall in water level in the northern part of the Biscayne Bay System, but significant phase differences in the southern part. This is especially true where tidal waves cross shallow banks, or where waves moving southward

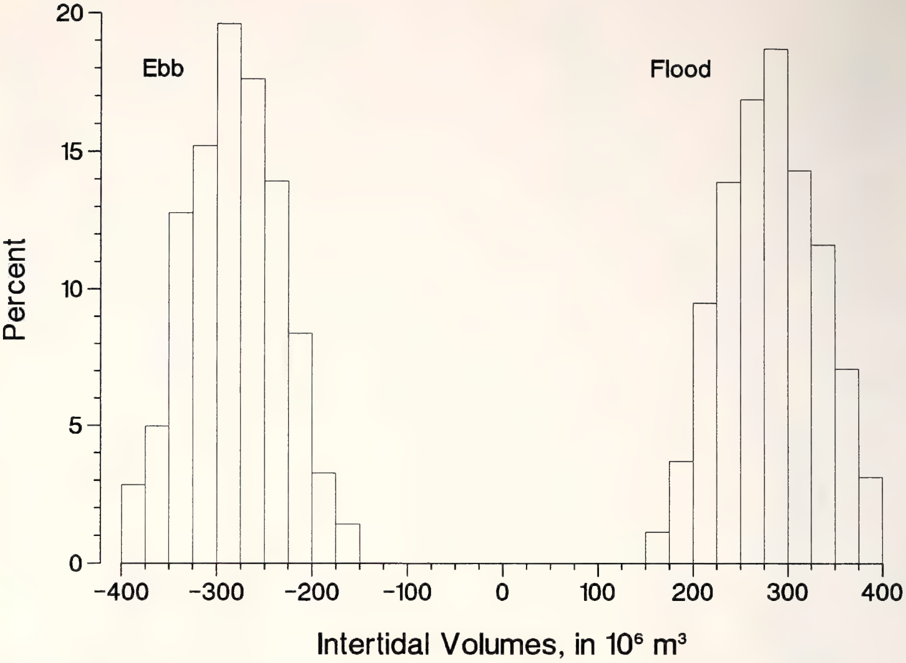

FIG. 7. Histograms of ebb tide (left) and flood tide (right) intertidal volumes, in 10^6 m^3, computed from a one-year simulation using the M_2, S_2, N_2, K_1 and O_1 tidal constituents. Bin size is 25 × 10^6 m^3.

out of Biscayne Bay interact with tidal waves entering through Caesar Creek, Broad Creek and Angelfish Creek.

The semidiurnal variation in bay volume varies considerably as tidal constituents cycle in and out of phase. The interaction of the M_2 and S_2 constituents alone produces spring tide bay intertidal volumes of 316 × 10^6 m^3 and neap tide intertidal volumes of 238 × 10^6 m^3 every 14.8 days. The interaction of the M_2 and N_2 constituents result in bay volume changes of between 222 and 332 × 10^6 m^3 every 27.55-day anomalistic month. The

TABLE 1. Harmonic constants of the principal tidal constituents of the total volume of Biscayne Bay, Card Sound, Little Card Sound, Barnes Sound and Manatee Bay. Amplitudes, Amp, in 10^6 m^3; local phase angles, Pha, in degrees.

	Amp	Pha
a. Semidiurnal Constituents		
M_2	134.0	271.7
S_2	19.3	308.2
N_2	26.2	252.7
b. Diurnal Constituents		
K_1	17.2	211.4
O_1	13.6	231.0

combined effect of the M_2, S_2 and N_2 constituents result in significant differences in successive spring and neap tides. Every second spring tide is reinforced, and every second neap tide is diminished. As a result, spring tide intertidal volumes can be as large as 368×10^6 m^3 and neap tide intertidal volumes can be as small as 186×10^6 m^3. The addition of diurnal constituents produces an even greater range in spring-neap extremes. Calculations using all five of the principal constituents indicate that neap tide intertidal volumes can be as small as 164×10^6 m^3, while spring tides can be as large as 394×10^6 m^3.

Co-amplitude and especially co-phase charts contain a degree of uncertainty when single 29-day water level records are used in microtidal environments. In the Biscayne Bay System study, 17 records were one synodic month long. The impact on the M_2 co-phase chart will be minimal because all M_2 amplitudes are 5 cm or greater. But in the southern part of the study area the other four tidal constituents have amplitudes of 1–2 cm. In Card Sound, Little Card Sound, Barnes Sound and Manatee Bay, even a deviation of ±0.5 cm can significantly change the position of an isopleth of amplitude. For the co-phase charts, the effect will be especially pronounced for the diurnal constituents. A 10° change in phase is a significant fraction of the 15° spacing of the isopleths.

Although the RMS deviations can alter the co-phase and co-amplitude charts significantly, uncertainty arising from single 29-day analyses has little effect on intertidal volume calculations. Most of the hour-by-hour change occurs from the rise and fall of the tide in the northern part of the bay system, where amplitudes are largest and RMS deviations are least. To quantify the effect of using results from single 29-day time series, bay volumes were recalculated, raising and then lowering amplitudes and phase angles by RMS values obtained from Equations (1) and (2). Adjustments were made only at the 17 stations for which harmonic constants were obtained from single 29-day harmonic analyses, and all amplitudes and phase angles were raised or lowered by the RMS value appropriate for the tidal constituent in question. Bay-shelf exchanges were largest when amplitudes were increased and phase angles were decreased, however the increase was only 0.35%. Exchanges were reduced by 0.4% when amplitudes were decreased and phase angles were increased.

The picture that emerges from this study is one of tidal waves entering the Biscayne Bay System primarily through the Safety Valve, but interacting with tidal waves entering through the three channels in southern Biscayne Bay and Card Sound to produce local perturbations in amplitude and phase angle. Spring tide intertidal volumes can be 2.4 times greater than neap tide values as the principal tidal constituents cycle in and out of phase. The 33 study sites within the 703 km^2 area of the Biscayne Bay System provide good spatial resolution for constructing co-amplitude and co-phase charts and especially for quantifying bay-shelf exchanges. Harmonic constants used in this study must be treated as at least slightly variable, however, and thus the co-amplitude and co-phase charts are subject to change as additional information becomes available.

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Biological Sciences

EFFECTS OF LIGHT AVAILABILITY ON HERBIVORY AND DEFENSE CHEMISTRY IN *PASSIFLORA INCARNATA.*

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ABSTRACT: Passiflora incarnata, *a perennial vine common in disturbed sites in central Florida, produces cyanogenic glycosides as a chemical defense against herbivores. The leaves are palatable, however, to specialist herbivore larvae of heliconiine butterflies including* Agraulis vanillae. *We investigated six different* P. incarnata *populations from sunny and partly shady sites to determine if this chemical defense is affected by light availability. In addition, we asked whether plants that had experienced herbivory in the field increased the production of cyanogenic glycosides. From each sun and shade population we collected leaves from plants that had previously experienced herbivory and from plants that had little or no evidence of herbivory, for a total of 251 plants sampled. Although there was significant variability in cyanide production among the six populations, it was not related to light environment. In addition to assaying for cyanide production, we asked whether the performance of* Agraulis vanillae *is affected by either the site of origin or previous herbivory experienced by* P. incarnata. *There was some evidence that sun and shade populations have different chemical responses to previous herbivory. Caterpillars tended to eat a greater amount of leaf tissue from branches that had not previously experienced herbivory with this difference being greatest in sun leaves. Caterpillar growth rate, however, was not affected by light availability or previous herbivory.*

HERBIVORY in natural plant communities is influenced by the effect of the physical environment on plants since resource availability can affect both the general nutritional quality of the plant as well as the level of chemical defense produced (Gershenzon, 1984). The availability of water (e.g., Scriber and Slansky, 1981; Mattson and Haack, 1987), nutrients (e.g., Glyphis and Puttick, 1989) and light can influence plant defense chemistry. Where light is limiting, for example, plants may reduce allocation of carbon to defense chemicals. Aide and Zimmerman (1990) found that tannin levels in the tropical liana *Connarus turczaninowii* were higher in sunny than shady environments. Levels of phenolic compounds have also been shown to increase with increasing light availability (Waterman et al., 1984; Larsson et al., 1986; Mole et al., 1988; Dudt and Shure, 1994).

These results support the idea that antiherbivore chemical production is constrained by resource availability and that populations of a single species may differ markedly in their level of defense as a function of their physical environment. Differences in allocation to defense chemistry *between* species from high and low resource environments, however, are not predicted to exhibit decreasing investment in defense with decreasing resource levels. Rather, between-species differences are theorized to reflect the evolutionary response to selection where there are tradeoffs between growth, reproduction and defense. In this case, low resource environments should favor plants with slow growth rates. Slow rates of growth subsequently favor large investments in antiherbivore defenses (Coley et al., 1985). Similar differences between populations within species may occur if selection favors these same allocation strategies in populations from different resource environments. Thus, differences in levels of defense detected between populations of field-grown plants may be strictly phenotypic (e.g., resource limitation may constrain allocation to chemical defense) or genetic (e.g., selection may favor greater investment in the production of defense chemicals in a resource-limited environment).

Cyanogenic glycosides are produced by all members of the genus *Passiflora* and are capable of releasing hydrogen cyanide (HCN) from damaged plant tissues. Because *Passiflora* produces cyanogenic glycosides, many generalist herbivores avoid them. There are at least 29 different cyanogenic compounds produced by members of *Passiflora* with many species producing two or more compounds (Spencer, 1988). This chemical variability among species may explain the coevolutionary relationship between *Passiflora* and their primary herbivores, the heliconiines (Benson et al., 1976). In fact, an exhaustive study of 51 heliconiine and 107 *Passiflora* species found that host plant chemistry appears to be central to the observed coevolutionary interaction between these two groups (Spencer, 1988). Despite a linked evolutionary history, there is not complete specialization by each butterfly species on a single *Passiflora* species. Based on the number of different *Passiflora* species used as a host for each of the 51 heliconiines, Spencer (1988) rated the butterfly species in order of the degree to which they specialize on a particular host. In his study, *A. vanillae* was able to exploit seven of 15 *Passiflora* subgenera that were analyzed and was able to tolerate five of six different structural classes of cyanogenic compounds. In addition, Spencer (1988) suggested that the sulfated cyanogens present in the subgenus to which *P. incarnata* belongs (*Granadilla*) are not highly specific in action and may provide a general, "quantitative" mode of defense (*sensu* Feeny, 1976). Quantitative defenses are broadly effective and tend to have an increasingly negative effect on the herbivore as levels of the chemical increase. Thus, although *A. vanillae* is considered a specialist herbivore of *P. incarnata,* and cyanogenic glycosides are typically considered "qualitative" defense chemicals that are ineffective against a specialist, there may be some deterrent effect of cyanogenic glycosides in *Passiflora* on *A. vanillae.*

To determine how herbivory on *P. incarnata* was influenced by light availability, we asked: 1) What is the effect of light availability on levels of cyanogenic glycosides produced? We assayed cyanide production from *Passiflora* leaves collected from three sun and three partially shaded populations to determine how chemical defense may be influenced by light. 2) Is the production of cyanogenic glycosides inducible in *Passiflora*? An inducible defense is one that is produced only in response to plant damage and often, though not always, results in the accumulation of defense chemicals in leaves that experience herbivore damage (Karban and Myers, 1989). To determine whether cyanide production is increased after exposure to herbivory we collected and assayed previously eaten and uneaten leaves from each of the sunny and shaded populations. 3) Is caterpillar growth or efficiency affected by levels of chemical defense compounds? We exposed *Agraulis vanillae* caterpillars to a subset of the leaves used in the cyanide assays and quantified their consumption and growth.

MATERIALS AND METHODS—*Species and study sites*—*Passiflora incarnata* is an herbaceous rhizomatous, perennial vine native to the southeastern United States. In Florida it occurs in open, disturbed sites as well as dry woods. We collected *P. incarnata* stems during the summer of 1999 from a total of seven field sites. Four sites were designated as "shaded" because of the presence of trees immediately above the vines. Three sites were designated as "sun" and were located in open fields. With the exception of one sun and one shaded site located within Ocala National Forest in Lake County, all sites were located near the city of DeLand in Volusia County, Florida.

Defense chemistry—To assay levels of cyanide produced by *P. incarnata* leaves, we collected vine segments from each of the seven field sites beginning on June 14, 1999 and ending on August 10, 1999. On a given day we visited two field sites—one sun and one shaded. From each of these sites, six vine segments consisting of the seven most apical leaves were obtained. Three of these were taken from plants with obvious caterpillar damage (i.e., leaves were eaten from the margins) on at least one of the collected leaves. The other three were taken from plants with no evidence of herbivory. We placed vine segments in water in ziplock plastic bags after collection.

We transported vine segments to the laboratory where randomly chosen leaves from each vine were removed to total approximately one gram of leaf tissue from each vine segment. All leaf tissue from a single vine was ground in dry ice using a mortar and pestle. This ground leaf tissue was placed in the outer well of a gas absorption dish. We added 1 ml of 1M NaOH solution to the center well prior to the addition of 1 ml of the phosphate buffer (pH 6.8) to the leaf tissue. The lid was applied to the absorption dish and all samples were incubated at 37°C overnight. The physical damage to the leaf caused by the grinding stimulated the production of cyanide gas that was then taken up by the NaOH. The NaOH solution was used in a series of reactions following the incubation procedure that detects the presence of cyanide colorimetrically using a spectrophotometer (Brinker and Seigler, 1989; Seigler, 1991). We used increasing concentrations of sodium cyanide to generate a standard curve relating the amount of cyanide and absorption wavelength.

Forty-two vines from each of two shaded and the three sun populations were sampled. One of the shaded populations used for twelve samples at the start of the study was discontinued due to problems with access to the site. An additional 29 samples were taken from an alternate shaded population. We assayed a total of 251 vine segments.

Caterpillar feeding trials—One hundred eight (18 from each of three sun and three shaded populations) of the 251 vines were also used in caterpillar feeding trials. For these trials, the cyanide assays were performed as described. In addition, as the leaf samples were incubating, digital photographs of the remaining leaves were obtained to quantify total leaf area. Vine segments, with two to four leaves remaining, were placed in individual 125 ml Erlenmeyer flasks with distilled water. Parafilm was used to seal the top of the flask around the stem. *Agraulis vanillae* caterpillars which had previously been collected from the field were weighed to the nearest 0.1 mg and a single caterpillar was immediately placed on each plant segment. Caterpillars were collected anywhere from a week to a few hours before the trial. Second instar larvae that had a mean weight of 0.1766g (standard deviation = 0.0884) were used in the trials. All flasks with vine segments and caterpillars were placed in a greenhouse. To prevent the escape of caterpillars and the build-up of heat in the greenhouse, cages constructed from 30% shade cloth were set around each flask. Caterpillars were left under these conditions for 42 to 48 hours (the time varied somewhat from trial to trial). In no case did a caterpillar completely consume all leaf material in their time on the stems.

After the feeding period caterpillars were removed from their respective plants and weighed. Digital photographs of the attacked leaves were taken and transferred to a Macintosh 7600 computer. The area of all leaves before and after feeding was calculated using the shareware program NIH Image v. 1.61 (National Institutes of Health 1998). Leaf area consumed by each caterpillar was then calculated and divided by the length of time that the caterpillar spent on the stem. Caterpillar relative growth rate (RGR) was calculated as:

$$\frac{\left(\frac{w_{\text{final}} - w_{\text{initial}}}{w_{\text{initial}}}\right)}{\text{Time}} \qquad (1)$$

where w_{final} = caterpillar weight at end of trial and w_{initial} = caterpillar weight at beginning of trial. Time was measured in days.

Data analysis—All dependent variables (i.e., μg cyanide/g leaf tissue, caterpillar RGR, and total leaf area eaten) were analyzed using an analysis of variance with Site (Sun vs. Shaded), Population nested within Site, and Previous Herbivory as main effects. Population(Site) was designated a random effect while all other effects were fixed.

RESULTS—Sun and shade sites did not differ in levels of cyanide produced from field-collected leaves although there was significant variability among the six populations studied (Table 1). In addition, a nearly significant interaction term (see Table 1, Previous Herbivory × Site effect, $p<0.10$) suggests that leaves from sun and shade sites differ in their chemical response to herbivory they experienced in the field. In particular, leaves from the sun that had previously experienced herbivory had lower levels of cyanide in our assays than those leaves that had not experienced herbivory. Shade leaves, however, produced similar levels of cyanide in our assay regardless of previous field herbivory (Fig. 1).

TABLE 1. Results of analysis of variance comparing µgrams of cyanide produced per gram of *Passiflora incarnata* leaf tissue among seven populations (four shade and three sun). Half of the leaves from each population had previously experienced herbivory in the field.

Effect	df	MS	F	P
Site	1	11.20	0.289	0.6130
Population (Site)	5	41.35	5.658	0.0001
Previous Herbivory	1	3.85	0.527	0.4690
Prev. Herb. × Site	1	22.48	3.075	0.0810
Error	242	7.31		

Neither *A. vanillae* caterpillar feeding nor growth followed the pattern predicted by the cyanide results. Caterpillars tended to eat more leaf area from branches that had not previously experienced herbivory in the field (Table 2; $p<0.1$). In addition, this response tended to be stronger for sun leaves than shade leaves (Table 2, $p<0.1$, Fig. 2). Thus, sun leaves that had previously experienced herbivory and had the lowest levels of cyanide assayed also had the lowest amount of leaf area removed by caterpillars in our feeding trials. Caterpillar RGR varied significantly among the six populations but there was no effect of Site (Table 3).

DISCUSSION—Detectable levels of cyanide varied significantly among the six populations of *P. incarnata.* Because the leaves used in the assays were collected from the field, these differences could have many possible causes that were not separable in this experiment. For example, differences in soil nutrients or other environmental factors among populations may affect levels of cyanogenic glycosides produced by plants (Dement and Mooney, 1974; Seigler, 1991). Alternatively, differences in defense chemistry among populations may have a genetic basis. In this experiment, however, populations

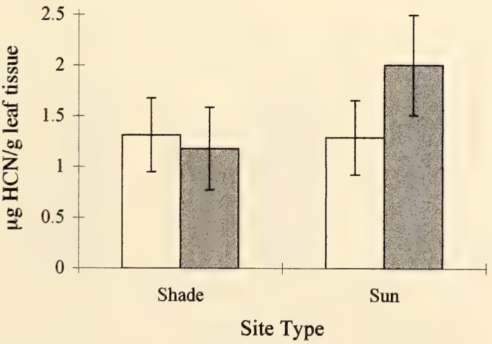

FIG. 1. Average amount of cyanide (HCN) detected in leaf assays from *P. incarnata* plants from sun and shaded sites. Leaves from each site were characterized as having been previously eaten by herbivores (□) or having experienced no previous herbivory (■). Bars indicate + 1 standard error.

TABLE 2. Results of analysis of variance comparing the amount of *P. incarnata* leaf tissue consumed by *Agraulis vanillae* caterpillars per day. Half of the leaves from each of six populations (three sun and three shaded) had previously experienced herbivory in the field.

Effect	df	MS	F	P
Site	1	344.24	0.282	0.635
Population (Site)	4	1221.81	6.218	0.0002
Previous Herbivory	1	607.86	3.093	0.0818
Prev. Herb. × Site	1	626.64	3.189	0.0773
Error	97	196.51		

from different light environments did not differ predictably in the production of cyanide.

There was some evidence, however, that leaves from sunny and shaded sites have different chemical responses to previous herbivory. By comparing levels of cyanide produced by leaves that had previously experienced herbivory and those that had not, we tested the idea that the production of cyanogenic glycosides is inducible (e.g., Georgiadis and McNaughton, 1988). Thus we predicted an increase in cyanide production in those plants that had previously experienced caterpillar damage. Counter to this prediction, we found a reduction in the production of defense compounds in previously eaten leaves from the sun population compared to sun leaves that were previously uneaten. Cyanide production in shade leaves varied less with exposure to previous herbivory than did sun leaves.

If damage to leaves by herbivores results in a passive deterioration of plant resources (Wellings and Dixon, 1987), cyanide levels, as well as levels of other metabolites necessary for growth and defense may be reduced following herbivory. Similarly, detectable cyanide levels may be reduced in branches that have previously experienced high levels of herbivory if the release of cyanide after herbivory has toxic effects on the leaf itself (Karban

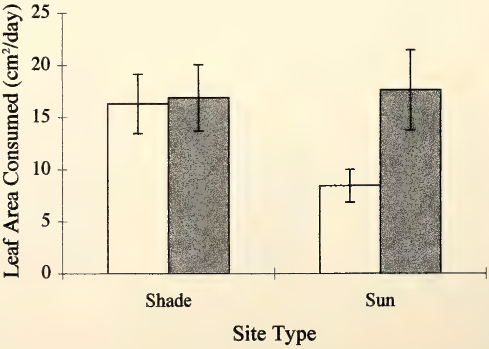

FIG. 2. Average amount of leaf area eaten by *A. vanillae* caterpillars fed leaves from sun and shaded sites of *P. incarnata*. Leaves from each site were characterized as having been previously eaten by herbivores (□) or having experienced no previous herbivory (□). Bars indicate + 1 standard error.

TABLE 3. Results of analysis of variance comparing the relative growth rate (RGR) of *Agraulis vanillae* caterpillars fed leaf tissue from six different *P. incarnata* populations. Half of the leaves from each of six populations (three sun and three shaded) had previously experienced herbivory in the field.

Effect	df	MS	F	P
Site	1	0.4687	0.7306	0.4408
Population (Site)	4	0.6428	4.3446	0.0028
Previous Herbivory	1	0.0366	0.2475	0.6200
Prev. Herb. × Site	1	0.0724	0.0489	0.4860
Error	96	0.1479		

and Myers, 1989). Such autotoxicity would negatively impact future cyanide production if, for example, the released cyanide destroys the vacuoles that harbor the cyanogenic glycosides (reviewed in Duffey and Felton, 1989). In addition, this negative effect on eaten leaves may have ramifications for other leaves on the same stem if there is resource-sharing. In this study (Bennington and Wheeler, unpublished data), and others (Louda and Rodman, 1996), leaves from sunny sites tended to have substantially greater amounts of herbivory than those from shade. Thus, the putative resource reductions in leaves from plants with previous herbivory would be expected to be greatest in leaves from sun sites. Both of these explanations are consistent with the finding that there was a tendency for caterpillars to eat less total leaf area from sun leaves that had previously experienced herbivory and that had lower levels of cyanide detected in our assays. If these leaves had reduced cyanide as a function of a general reduction in resources to the leaf, caterpillars may eat less leaf area (e.g., Coley, 1983). Some studies, however, have found increased feeding rates on nutritionally-reduced foliage (e.g., Slansky and Feeny, 1977). Additionally, some studies have found that high levels of defense chemicals induced by herbivore damage can stimulate additional herbivory by specialist herbivores while deterring generalists (e.g., Giamoustaris and Mithen, 1995).

There was significant variability among populations in both cyanide production and caterpillar RGR, but populations with high cyanide levels were not necessarily those with low caterpillar RGR. Although there was not a negative relationship between leaf cyanide production and caterpillar RGR (results not shown), there was more variability in RGR in leaves with low cyanide levels and the highest RGRs occurred at the lowest levels of cyanide. This may be a function of the fact that *A. vanillae,* while not a strict specialist, is a voracious feeder of *P. incarnata* and is capable of easily tolerating the amount of cyanide produced by most plants, but experiences some negative effects when levels of defense compounds are highest. Herbivores that are more generalist feeders may have a different response (Tallamy and Krischik, 1989; Agrawal, 2000).

The time required to assay cyanide and to set up feeding trials necessitated the relatively small sample sizes used here. This reduced our ability to detect significant effects in our analyses given the large variance associated with dependent variables involving both the plant and the caterpillar. The majority of this variance originated from the field collection of leaves and larvae which introduced many sources of environmental variability. Because we used field-collected leaves, we were unable to quantify the time at which herbivore damage occurred or to control the amount of herbivory on each stem. Similarly, field-collected caterpillars were chosen for each trial based on their size. However, some were closer to molting to third instar than others. This caused some to molt during the 48 hours of the experiment while others did not. This increased variance among caterpillars in the amount of leaf material they consumed and in the amount of weight they gained. In an attempt to reduce environment-induced variability among leaves, we initially used greenhouse grown *P. incarnata* seedlings in our chemical assays and feeding trials. Interestingly, we were rarely able to detect the presence of cyanide in these young plants using our standard colorimetric assay. It is not clear whether this was a function of the age of the plants or to the lack of natural herbivores present in the greenhouse.

Our data suggest many possible variables that may influence the production of cyanogenic glycosides in *P. incarnata.* The observed variability among populations may be a function of genetic differences or phenotypic differences that result from environmental variation. The tendency for low production of cyanide by sun leaves that have experienced herbivory requires additional investigation into potential mechanisms. Controlled experiments using intact plants (to reduce effects of cutting on leaf chemistry) and lab-reared caterpillars are needed for further investigation into this system. In addition, larvae of *Heliconius charitonia,* another specialist herbivore of *P. incarnata* in central Florida, should be used in feeding trials to compare their response to that of *A. vanillae.* This comparison would be especially interesting given that caterpillars of this species appear to be restricted to shady populations of *P. incarnata* while *A. vanilla* occurs most commonly in sunnier sites (Bennington and Wheeler, unpublished data).

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GROSS BRAIN MORPHOLOGY IN THE YELLOW STINGRAY, *UROBATIS JAMAICENSIS*

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ABSTRACT: *The yellow stingray,* Urobatis jamaicensis *(family Urolophidae), a short-lived, relatively small elasmobranch species (35–40 cm total length), is a common inhabitant of hard bottom and coral reef communities in southeastern Florida and many parts of the Caribbean. A paucity of published studies deal with the yellow stingray, none however on the gross morphology of its nervous system. The gross brain structure of the yellow stingray is compared with previously published studies on other batoid elasmobranchs. The external brain structure of* Urobatis jamaicensis *was similar to that reported for other Dasyatids, including presence of an asymmetric cerebellum. The bilaterally symmetric brain is well developed and quite large in proportion to body size (≈1–2% bw). Stingrays generally possess a brain three to 10 times the size of their sister groups, the electric rays, guitarfish, and skates (Northcutt, 1989), the yellow stingray is no exception.*

THE YELLOW stingray, *Urobatis jamaicensis,* is a short-lived, small elasmobranch species (35–45 cm TL), commonly inhabiting hard bottom and coral reef communities of southeastern Florida. Its small size, ease of capture, and large abundance makes it an ideal candidate for many ecological and physiological studies. We used this species to examine the elasmobranch histaminergic system since there is a paucity of published studies dealing with the yellow stingray, and, to our knowledge, none on its nervous system. We compared gross brain structure of the yellow stingray with previously published studies on other batoid elasmobranchs to better understand its nervous system.

MATERIALS AND METHODS—Three male and two female sexually mature yellow rays captured on the inshore hard bottom community off Dania Beach, FL were killed with a lethal dose of MS-222 (Finquel, tricaine methanesulfonate). The dorsal side of the brain case was dissected in two males and two females, allowing an untouched look at the brain placement in the skull. Eye muscles of the third male were dissected and a longitudinal section of the brain was made to find cranial nerves IV and VI. Dorsal and ventral aspects were illustrated (Fig. 1).

RESULTS AND DISCUSSION—Most previous work on *Urobatis* sp. focused on aspects of behavior or ecology. A few studies investigated aspects of the nervous system in the genus, for example, the innervation of the gills (Donald, 1988) and clasper control (Liu and Demski, 1993); however, the gross morphology of the yellow stingray's brain has been overlooked. Conversely, the gross brain morphology of several other elasmobranch species has been well documented (Hofmann, 1999; Northcutt, 1978). Extensive studies have been conducted with the closely related *Dasyatis sabina* such as the documentation of age-related increase in neuronal and axonal numbers in the ventral horn (Leonard et al., 1978), the identification of the midbrain loco-

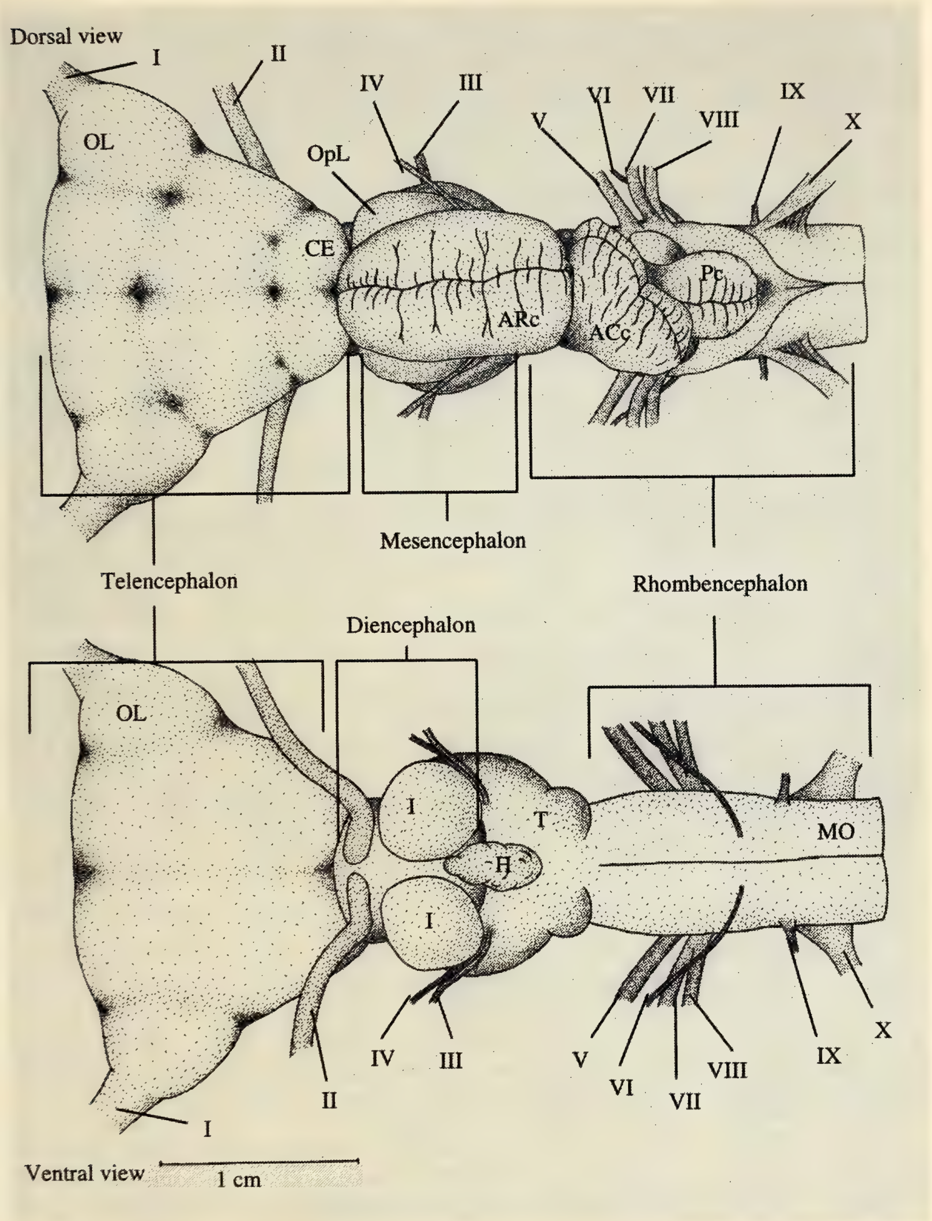

FIG. 1. Dorsal and ventral view with cranial nerves and major topography. Cranial Nerves: I—Olfactory, II—Optic, III—Oculomotor, IV—Trochlear, V—Trigeminal, VI—Abducens, VII—Facial, VII—Auditory, IX—Glossopharyngeal, X—Vagus. Major Topography: ACc—Anterior caudal cerebellum, ARc—Anterior rostral cerebellum, CE—Cerebrum, H—Hypophysis, I—Inferior lobes of infundibulum, MO—Medulla oblongata, OL—Olfactory lobe, OpL—Optic Lobe, Pc—Posterior cerebellum, T—Tegmentum.

motor region and its relation to descending locomotor pathways (Bernau et al., 1991), and most recently, mapping the morphology of the mechanosensory lateral line system (Maruska and Tricas, 1998).

The external brain structure of *U. jamaicensis* is similar to that reported for other Dasyatids, including presence of an asymmetric anterior caudal cerebellum (Fig. 1). Comparatively, stingrays possess a brain three to 10 times the size of its sister groups, the electric rays, guitarfish, and skates (Northcutt, 1989). The yellow stingray is no exception. Its mostly bilaterally symmetric brain is well developed and quite large in proportion to body size (≈1–2% bw).

The telencephalon (Fig. 1), the largest and most anterior portion, extends two thick short olfactory tracts (cranial nerve I) to the olfactory bulbs in the anterior portion of the head. The diencephalon (Fig. 1) extends ventrally caudal to the telencephalon. This area contains the large optic nerves (II), the inferior lobe of the infundibulum, and the hypophysis.

The mesencephalon (Fig. 1), a pronounced bulbous feature in the middle of the brain caudal and dorsal to the diencephalon, is comprised of the optic lobe (dorsal) and the tegmentum (ventral). Two distinctive oculomotor nerves (III) extend out from the ventral side of the mesencephalon. The trochlear nerve (IV) extends rostrally from the dorsal caudal section of the optic lobe.

The rhombencephalon (Fig. 1), the most posterior portion of the brain, comprises the cerebellum, the trigeminal (V), abducens (VI), facial (VII), auditory (VIII), glossopharyngeal (IX), the vagus nerves (X), and the medulla oblongata. The rhombencephalon extends caudally out of the brain case, into the spinal cord, which extends to the tail of the animal.

The cerebellum is heavily reticulated and covers the entire dorsal surface of the mesencephalon and most of the rhombencephalon. It is split into three distinct parts, the anterior rostral, the anterior caudal, and the posterior cerebellum. The anterior caudal portion of the cerebellum is the only part that exhibits asymmetry in the yellow stingray brain (Fig. 1, dorsal view). The yellow stingray did not exhibit variations in anterior rostral cerebellar morphology as seen in the Atlantic stingray, *Dasyatis sabina* (Puzdrowski and Leonard, 1992).

The yellow stingray possesses a brain two times the size of the clearnose skate, *Raja eglanteria,* and the thornback skate, *Platyrhinoidis triseriata,* and a proportionately larger telencephalon. This feature in *U. jamaicensis* is similar to the bat ray, *Myliobatis californica,* the southern stingray *D. americana,* and the Atlantic stingray, *D. sabina* (Northcutt, 1978). Contrary to the telencephalon, the cerebellum in the yellow stingray is much less complex than the bat ray or southern stingray, and more closely resembles the Atlantic stingray (Puzdrowski and Leonard, 1992).

The nerves in the yellow stingray vary from other elasmobranchs as well. In the spiny dogfish, *Squalus acanthias,* the trigeminal (V), facial (VII), and auditory (VIII) nerves exit the brain in a single trunk (Gilbert, 1989), however, in the yellow stingray and other closely related elasmobranch species, including *D. sabina,* the trigeminal (V) is a distinct, separate trunk. Another interesting feature is the vagus (X). This nerve appears as a bundle of seven to eight nerves exiting the brain in a single place (Fig. 1, dorsal view). Similar to other skates and rays, these nerves are separate, but are bundled together into seemingly one large nerve that exits the brain case before splitting to innervate the heart, gills, stomach, intestine, pharynx, esophagus, and body wall.

Compared to the morphology and function of other stingray species nervous systems, we found the yellow stingray brain morphology to be most similar to *Dasyatis sabina* in form. Further investigations into other Urolophids will likely provide similar results.

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Environmental Chemistry

BACKGROUND CHARACTERISTICS OF GROUNDWATER IN THE SURFICIAL AQUIFER OF KENNEDY SPACE CENTER, MERRITT ISLAND, FLORIDA

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ABSTRACT: *The Surficial Aquifer on Kennedy Space Center, Merritt Island, Florida occurs in unconsolidated Pleistocene and Holocene deposits; it is divided into four subaquifers (Dune, Dune-Swale, West Plain, Marsh) based on recharge areas and groundwater characteristics. We determined background characteristics from shallow (4.6 m, N = 24), intermediate (10.7 m, N = 16), and deep (15.2 m, N = 11) wells distributed among the four subaquifers. Wells were located away from known contamination. Organochlorine pesticides, aroclors, and chlorinated herbicides were below detection in all samples. Seven polycyclic aromatic hydrocarbons (PAH) occurred at low frequencies and concentrations at shallow depths of the Dune, Dune-Swale, and West Plain subaquifers. PAHs are present in soils and have both natural and anthropogenic sources. Most trace elements were below detection or in low concentrations. Only Al, Ca,* Cl^-, Fe, Mg, Mn, K, and Na along with total dissolved solids (TDS), total organic carbon (TOC), conductivity, pH, dissolved oxygen (DO), and temperature could be compared among subaquifers and depths. Ca, Cl^-, Mg, Mn, K, Na, TDS, conductivity, and temperature differed with subaquifer and depth (ANOVA). These trends reflected increased mineralization with depth and interactions of the Dune and Marsh subaquifers with saline ocean and lagoon waters.

UNCONSOLIDATED, surficial aquifers are subject to contamination from point sources and from general land use, and contaminants may include trace elements, pesticides, herbicides, and other organics (Page, 1981; Burkart and Kolpin, 1993; Kolpin et al., 1995; 1998; Barbash et al., 1999). Urban and agricultural land uses have affected some Florida aquifers (Rutledge, 1987; Barbash and Resek, 1996).

John F. Kennedy Space Center (KSC) has been the primary launch complex for the United States Space Program since the 1960s. Various hazardous materials have been used in the operation of this launch complex leading to contamination concerns. Point source contamination to the KSC Surficial Aquifer has occurred at certain facilities (Edward E. Clark Engineers-Scientists, Inc., 1985, 1987a, 1987b) [hereafter referenced as Clark]. Investigation and in some cases remediation of sites that may have been contaminated is required under the Resource Conservation and Recovery Act (RCRA). Investigation of such sites requires comparing chemical parameters of the site to screening values. State or regional screening values may not represent background values of a local environment. In this study, we developed background values for chemical composition of groundwater of the surficial aquifer specific to KSC. Few comprehensive data are available on the background chemical composition of the Surficial Aquifer in coastal, central Florida.

Kennedy Space Center is located on the east coast of central Florida in Brevard County, at approximately 28.5 degrees north latitude and 81.7 degrees west longitude. KSC is located on Merritt Island, a relict barrier island. Cape Canaveral Air Force Station (CCAFS) occupies the adjacent Cape Canaveral barrier island. Large water bodies surround these lands: the Atlantic Ocean, Banana River, Indian River, and Mosquito Lagoon.

The climate is warm and humid with mean annual precipitation of 136.6 cm (Mailander, 1990). The wet season extends from May to October and the rest of the year is relatively dry. Year-to-year variability in precipitation is high.

Florida has a complex geologic history with repeated periods of deposition when the Florida Plateau was submerged and erosion when the seas recessed (Randazzo, 1997; Scott, 1997). The oldest formations known to occur beneath KSC are Eocene limestones (Cooke, 1945). Following another period of recession of the sea and erosion of the land surface, the Hawthorn formation of calcareous clay, phosphatic limestone, phosphorite, and radiolarian clay was deposited in the late Miocene (Cooke, 1945; Brown et al., 1962). Overlying this are unconsolidated beds of fine sand, shells, clay, and calcareous clay of late Miocene or Pliocene age (Brown et al., 1962). Surface strata are primarily unconsolidated white to brown quartz sand containing beds of sandy coquina of Pleistocene and Holocene age (Brown et al., 1962; Parkinson, 2000).

The alternating high and low sea stands of the Pleistocene and Holocene (Field and Duane, 1974; Bowen, 1978; Delcourt and Delcourt, 1981) shaped the surface of KSC and Brevard County. The outer barrier island and Cape Canaveral formed after sea levels rose when the Wisconsinan glaciers retreated (Davis, 1997). Merritt Island also formed as a prograding barrier island complex; the eastern edge of Merritt Island at its contact with the Mosquito Lagoon and the Banana River forms a relict cape aligned with False Cape (White, 1958, 1970). Multiple dune ridges apparently represent successive stages in this growth. Brooks (1972) suggested that the geologic history of the Merritt Island-Cape Canaveral barrier island was complex. The western portion of Merritt Island is substantially older than the east (Brooks, 1972; Clapp, 1987). Erosion has reduced the western side to a nearly level plain (Brown et al., 1962).

The geologic structure and composition of the Merritt Island-Cape Canaveral barrier island complex together with climatic conditions form the basis for the hydrology of the system. Groundwater hydrology of KSC has been the subject of several studies (e.g., Clark, 1985, 1987a, 1987b, 1987c).

The Surficial Aquifer is extremely important since it supports the freshwater wetlands and provides fresh groundwater discharge to the surrounding subsaline lagoons (Clark, 1987c). It occurs in the saturated part of the moderately permeable Pleistocene and Holocene deposits of fine to medium sand, shell, coquina, silts, and marl. Its upper boundary is the water table and the lower boundary is the confining unit at the base of the Pleistocene and Holocene deposits. Recharge is by direct infiltration of rainfall. The higher sand ridges in the center of the island are particularly important for recharge. These ridges are relatively high, composed of permeable sands, and infiltration is less restricted by subsurface hardpans than in other areas. From these prime recharge areas, groundwater flows east and west toward the lagoon systems and the ocean. Discharge from the surface aquifer is from evapotranspiration, seepage into canals and ditches, seepage into interior wetland swales, and seepage into impoundments, lagoons, and the ocean. Most of the seepage into interior wetland swales is subsequently lost to evapotranspiration. Seasonal fluctations in the water table occur with changes in precipitation and evapotranspiration. The water table is highest late in the wet season (typically September–October) and drops as precipitation declines. In the winter, evapotranspiration is low as temperatures decline and some of the vegetation is dormant. In spring, evapotranspiration increases and the water table may decline during spring droughts (Clark, 1987c; Mailander, 1990).

The Surficial Aquifer can be divided into several subsystems (Fig. 1). The Dune (Barrier Island) subsystem has a lens of freshwater less than 3 m thick on top of intruded saline water. The primary dune acts as the prime recharge area. Shallow groundwater flows east of the ridge to the Atlantic Ocean and west to Banana River, Mosquito Lagoon, or swales; at depth (> 6.1 m) flow is to the Atlantic Ocean. The Dune-Swale subsystem includes the high ridges with permeable sand that favor recharge. This is the only area where the freshwater recharge of the deeper layers of the Surficial Aquifer occurs. During most of the year, shallow groundwater discharges to the swales. At the beginning of the rainy season after the spring drought, swales collect water and remain flooded; lateral and downward seepage from the swales helps to recharge the groundwater. In areas of pine flatwoods and swales, topography is lower and most soils have well-developed humic hardpans (spodic horizon, Bh layer) that restrict infiltration. During heavy rains, water perches above the hardpan and infiltrates slowly into the Surficial Aquifer. This increases evapotranspiration and reduces recharge relative to the prime recharge areas. In the West Plain and Marsh (Lowland) subsystems, the water table is typically within 0.9 m of the land surface, evapotranspiration losses are high, and the dispersed saline water interface renders water quality variable. In the West Plain south of Banana Creek, a limerock "hardpan" replaces the humic hardpan of the Dune-Swale flatwoods. Along the coastlines, the Surficial Aquifer contacts the saline water of the Atlantic Ocean and the brackish lagoons. Seawater intrusion occurs as a wedge at the base of the Surficial Aquifer since seawater is denser than fresh water.

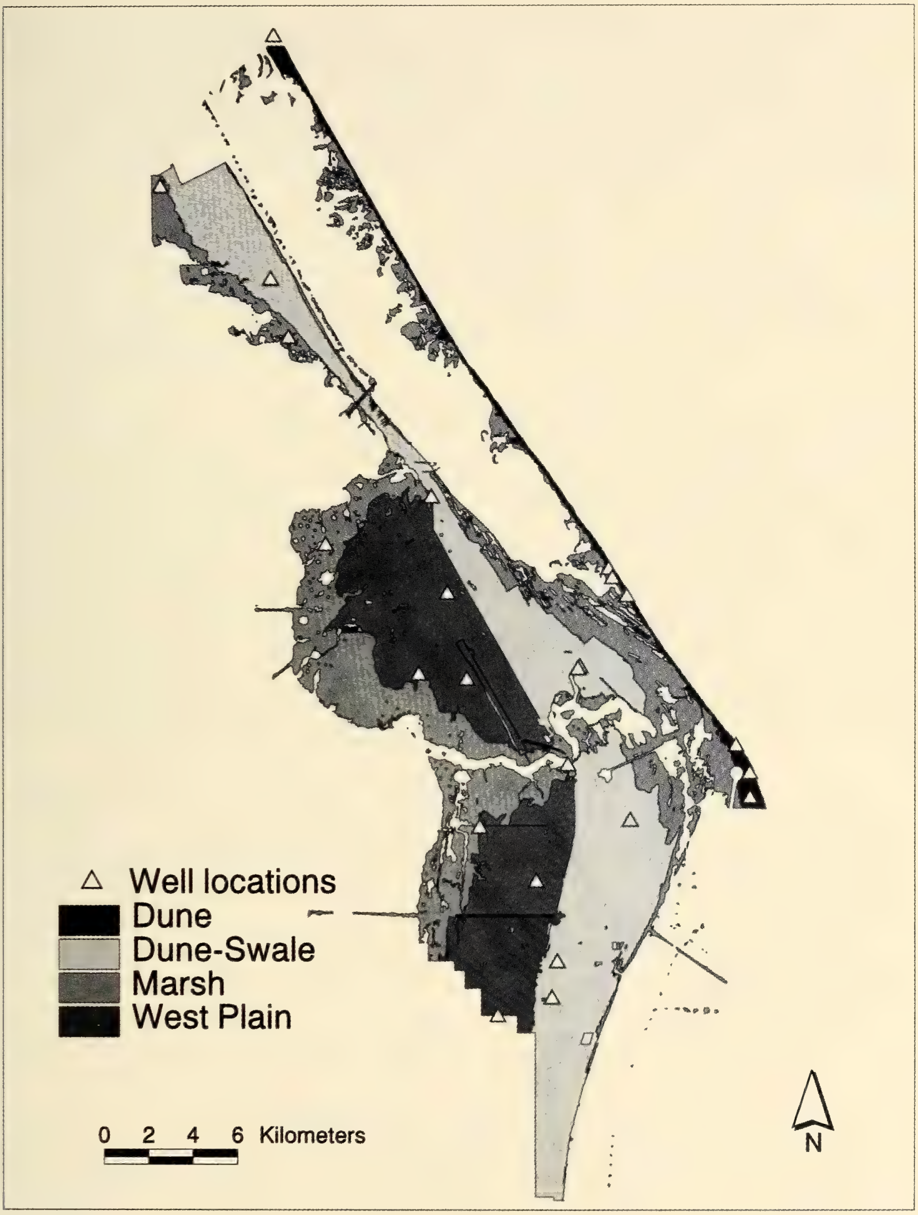


FIG. 1. Distribution of subaquifers of the Surficial Aquifer on Kennedy Space Center and locations of sample wells. Subaquifer boundaries adapted from Clark (1987c).

The position of the fresh-saline water interface fluctuates; when water levels are low, saline water moves inland, and when water levels are high, saline water is forced out, producing a dynamic system (Clark, 1987c).

Other aquifers beneath KSC include the artesian Floridan Aquifer, associated with the Eocene limestones. Secondary artesian aquifers occur within the Hawthorn formation and the Caloosahatchee Marl Equivalent. The artesian aquifers have little direct influence on surface conditions; however, artesian wells have been used to irrigate orange groves and previously to maintain water levels in some mosquito impoundments on Merritt Island (Clark, 1987c).

METHODS—*Site selection*—We used the four subsystems of the Surficial Aquifer (Fig. 1), originally delineated by Clark (1987c), as the basis for sample site locations. We located six sample sites in each subsystem, 24 total sites (Fig. 1). Sites were away from known contamination. One to three wells were installed at these sites. The sampling plan designated that a shallow well (4.6 m) was to be installed at each site. Intermediate wells (10.7 m) were to be installed at four sites per subsystem (16 total); deep wells (15.2 m) were to be installed at three sites per subsystem (12 total). A total of 52 wells were planned.

Universal Engineering Sciences, Inc. installed groundwater wells in August and September 1998 (Universal Engineering Sciences, Inc., 1998). Due to the depth of the confining unit at one location, the deep well was not installed. Therefore, a total of 51 wells were installed at varying depths. Wells were installed with a truck-mounted drill rig and hollow-stem auger (6.25 in, 15.9 cm inside diameter). Auger assemblies were cleaned and decontaminated before each use. Each well was constructed with two-inch (5 cm) diameter PVC casing, 30/65 fine sand was used as a filter pack, and No. 6 (0.006-inch, 0.15 mm) slotted well screen was used. A bentonite seal (6–12 inch, 15–30 cm) was used above the filter pack, and the rest of the annular space was grouted with cement (Universal Engineering Sciences, Inc., 1998). Well construction information (Universal Engineering Sciences, Inc., 1998) was consistent with well placement in the Surficial Aquifer; no confining layers were encountered in completed wells.

Sampling—Groundwater samples were collected from 51 wells: 24 shallow, 16 intermediate, and 11 deep. Samples were collected in September through November 1998; one well was sampled in January 1999 due to problems with its initial installation. Shallow and intermediate wells were screened for 3 m and deep wells for 1.5 m (Universal Engineering Sciences, Inc., 1998). Sample collection and chemical analyses were conducted by Environmental Conservation Laboratories (ENCO) following standard procedures (NASA, 1996). All well sampling was done using a low flow peristaltic pump (with Teflon check valves) and silicon and Tygon tubing. Turbidity was measured in the field throughout purging, and samples were collected when turbidity was <10 NTU (nephelometric turbidity units). Dissolved oxygen, pH, specific conductivity, and temperature were also measured in the field. Quality assurance/quality control samples were collected.

Chemical analysis—Groundwater samples were analyzed for organochlorine pesticides, aroclors, and chlorinated herbicides using gas chromatography and for polycyclic aromatic hydrocarbons (PAH) using high-pressure liquid chromatography (USEPA, 1996; EPA Methods 8081, 8082, 8151, and 8310). Organochlorine pesticides and degradation products analyzed for included: DDD, DDE, DDT, Aldrin, Alpha-BHC, Beta-BHC, Chlordane (alpha, gamma, and total), Delta-BHC, Dieldrin, Endosulfan I, Endosulfan II (beta), Endosulfan Sulfate, Endrin, Endrin Aldehyde, Endrin Ketone, Gamma-BHC (Lindane), Heptachlor, Heptachlor Epoxide (a and b), Isodrin, Methoxychlor, Mirex, and Toxaphene. Aroclors analyzed for included: PCB-1016/1242, PCB −1221, PCB −1232, PCB −1248, PCB −1254, and PCB −1260. Chlorinated herbicides analyzed for included: 2,4,5-TP (Silvex), 2,4,5-T, 2,4-D, 3,5-DCBA, 2,4-DB, 4-Nitrophenol, Acifluorfen, Bentazon, Chloramben, Dacthal, Dalapon, Dicamba, Dichloroprop, MCPA, MCPP, Pentachlorophenol, and Picloram. PAHs analyzed for included: 1-methylnaphthalane, 2-methylnaphthalane, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluroanthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluroanthene, fluorene, ideno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene.

Total concentrations of selected elements were analyzed using inductively coupled plasma-atomic emission spectrometry, atomic absorption-direct aspiration flame absorption, atomic absorption-furnace absorption, or cold-vapor-atomic absorption (USEPA, 1983, 1996). Methods (EPA) included 200.7 (Al, As, Ba, Be, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Ni, Se, Ag, V, Zn), 204.2 (Sb), 220.1 (Cu), 245.1 (Hg), 258.1 (K), 273.1 (Na), and 279.2 (Tl). Chloride was analyzed using a titrimetric mercuric nitrate technique (USEPA, 1983; EPA Method 325.3). Field analyses of groundwater samples for dissolved oxygen, turbidity, pH, specific conductivity, and temperature were conducted with calibrated instruments. Total dissolved solids (TDS) were determined using filtration followed by drying at 180 C (USEPA, 1983; EPA Method 160.1). Total organic carbon (TOC) was determined using catalytic combustion or wet chemical oxidation (USEPA, 1983; EPA Method 415.1).

Data analysis—We conducted data analyses using SPSS Version 9 (SPSS Inc., 1999). We determined the frequency of parameters occurring above the detection limits. We used boxplots to scan for obvious outliers in the data. Normality of distributions was tested using normality plots and the Kolmogorov-Smirnov statistics with Lilliefors significance levels. Where the sample size of data above detection was sufficient, we used two-way analysis of variance (ANOVA) to test for differences related to aquifer subsystem and depth. Subaquifer and depth were fixed effects. Chemistry data were transformed ($\log_{10}$) to enhance normality. Replicate samples were excluded from ANOVA. We examined patterns of correlations among selected parameters with principal components analysis (PCA) (PC-ORD, McCune and Mefford, 1999).

The occurrence of data below detection levels is a complication for data analysis and interpretation. Various approaches can be taken (e.g., Breckenridge and Crockett, 1995). Here one-half the detection level was substituted for values below detection (USEPA, 1998). No summary statistics were reported where all values were below detection.

RESULTS—All organochlorine pesticides (25), aroclors (6), and chlorinated herbicides (18) were below detection in all samples (Schmalzer et al., 2000). Ten PAHs were above detection in one to four samples. Eight PAHs (1-methylnaphthalene, 2- methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, and naphthalene) were below detection in all samples. Three PAHs (fluorene, phenanthrene, and pyrene) were present in only one sample at a level above the method detection level but below the practical quantitation level and are not considered further. Cobalt and mercury were always below detection. Beryllium, silver, and zinc were above detection in just one sample each (Table 1).

For some parameters, frequency of occurrence above detection varied with subaquifer or depth (Table 1). PAHs were above detection only in shallow wells of the Dune, Dune-Swale, and West Plain subaquifers (Table 1). Arsenic and cadmium were most frequently above detection in the Dune subaquifer.

Some elements differed among subaquifers and depths (Table 2). Only Al, Ca, Cl^-, Fe, Mg, Mn, K, and Na were above detection in sufficient samples to compare concentrations. In addition, TDS, TOC, specific conductivity, pH, dissolved oxygen (DO), and field temperature could be compared. The distributions of all parameters except temperature were not normal (Kolmogorov-Smirnov tests, $p<0.001$). Transformations ($\log_{10}$) im-

TABLE 1. Frequency (percent) of values greater than detection limits for chemical parameters in groundwater by subaquifer and depth. Only parameters greater than detection limits in at least one sample are shown.

Parameter	All ground-water	Dune shallow	Dune inter-mediate	Dune deep	Dune-swale shallow	Dune-swale inter-mediate	Dune-swale deep	West shallow	West inter-mediate	West deep	Marsh shallow	Marsh inter-mediate	Marsh deep
Sample Size	57	6	5	3	7	4	3	7	5	3	7	5	2
PAHs													
Benzo(a)anthracene	7.0	16.7	0	0	14.3	0	0	28.6	0	0	0	0	0
Benzo(a)pyrene	7.0	16.7	0	0	14.3	0	0	28.6	0	0	0	0	0
Benzo(b)fluoranthene	1.8	0	0	0	0	0	0	14.3	0	0	0	0	0
Benzo(k)fluoranthene	5.3	33.3	0	0	0	0	0	14.3	0	0	0	0	0
Chrysene	5.3	16.7	0	0	14.3	0	0	14.3	0	0	0	0	0
Fluoranthene	3.5	0	0	0	14.3	0	0	14.3	0	0	0	0	0
Indeno(1,2,3-cd)pyrene	3.5	16.7	0	0	0	0	0	14.3	0	0	0	0	0
Elements													
Aluminum	66.7	66.7	100.0	33.3	57.1	75.0	33.3	71.4	40.0	0	85.7	100.0	100.0
Antimony	8.8	0	40.0	0	0	0	33.3	0	0	0	28.6	0	0
Arsenic	22.8	50.0	60.0	66.7	0	0	0	14.3	20.0	0	42.9	0	0
Barium	5.3	0	0	0	0	0	0	0	0	0	28.6	20.0	0
Beryllium	1.8	0	20.0	0	0	0	0	0	0	0	0	0	0
Cadmium	7.0	16.7	20.0	33.3	14.3	0	0	0	0	0	0	0	0
Calcium	98.2	100.0	100.0	100.0	85.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Chloride	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Chromium (total)	5.3	0	20.0	0	0	0	0	0	0	0	28.6	0	0
Copper	7.0	0	20.0	0	0	0	0	0	0	33.3	14.3	20.0	0
Iron	77.2	16.7	60.0	100.0	100.0	100.0	66.7	85.7	100.0	100.0	71.4	80.0	50.0
Lead	14.0	0	60.0	33.3	0	0	0	0	0	33.3	14.3	40.0	0
Magnesium	96.5	100.0	100.0	100.0	71.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manganese	70.2	33.3	80.0	66.7	14.3	50.0	66.7	100.0	100.0	100.0	71.4	100.0	100.0
Nickel	3.5	0	20.0	0	0	0	0	0	0	33.3	0	0	0
Potassium	87.7	83.3	100.0	100.0	71.4	50.0	33.3	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 1. Continued.

Parameter	All groundwater	Dune shallow	Dune intermediate	Dune deep	Dune-swale shallow	Dune-swale intermediate	Dune-swale deep	West shallow	West intermediate	West deep	Marsh shallow	Marsh intermediate	Marsh deep
Selenium	7.0	0	40.0	0	28.6	0	0	0	0	0	0	0	0
Silver	1.8	0	0	33.3	0	0	0	0	0	0	0	0	0
Sodium	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Thallium	12.3	0	0	0	0	0	33.3	0	40.0	0	14.3	40.0	50.0
Vanadium	7.0	0	20.0	0	0	0	0	14.3	0	0	28.6	0	0
Zinc	1.8	0	0	0	0	0	0	0	0	33.3	0	0	0
Other Parameters													
Total Dissolved Solids	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total Organic Carbon	93.0	66.7	80.0	66.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 2. Chemical parameters in groundwater by subaquifer and depth. Data are means with standard deviations in parentheses. Field parameters were not measured on replicate samples. nd indicates all samples below detection limits.

Parameter	All groundwater	Dune shallow	Dune intermediate	Dune deep	Dune-swale shallow
Sample Size	57	6	5	3	7
PAHs					
Benzo(a)anthracene	0.035	0.047	0.03	0.03	0.036
(μg/L)	(0.02)	(0.041)	nd	nd	(0.015)
Benzo(a)pyrene	0.029	0.031	0.025	0.025	0.031
(μg/L)	(0.017)	(0.014)	nd	nd	(0.013)
Benzo(b)fluoranthene	0.05	0.05	0.05	0.05	0.051
(μg/L)	(0.02)	nd	nd	nd	nd
Benzo(k)fluoranthene	0.028	0.037	0.025	0.025	0.026
(μg/L)	(0.019)	(0.019)	nd	nd	nd
Chrysene	0.03	0.05	0.025	0.025	0.031
(μg/L)	(0.03)	(0.06)	nd	nd	(0.013)
Fluoranthene	0.06	0.05	0.05	0.05	0.06
(μg/L)	(0.08)	nd	nd	nd	(0.03)
Indeno(1,2,3-cd)pyrene	0.03	0.04	0.025	0.025	0.026
(μg/L)	(0.01)	(0.03)	nd	nd	nd
Elements					
Aluminum	0.16	0.083	0.105	0.05	0.298
(mg/L)	(0.27)	(0.098)	(0.025)	(0.04)	(0.481)
Antimony	0.003	0.003	0.007	0.0025	0.0025
(mg/L)	(0.002)	nd	(0.004)	nd	nd
Arsenic	0.011	0.015	0.028	0.021	0.005
(mg/L)	(0.016)	(0.02)	(0.039)	(0.014)	nd
Barium	0.06	0.05	0.05	0.05	0.05
(mg/L)	(0.05)	nd	nd	nd	nd
Beryllium	0.0005	0.0005	0.001	0.0005	0.0005
(mg/L)	(0.0003)	nd	(0.001)	nd	nd
Cadmium	0.0007	0.0008	0.002	0.0007	0.0006
(mg/L)	(0.0011)	(0.0006)	(0.004)	(0.0003)	(0.0002)
Calcium	242.4	148.8	322.4	336.7	56.1
(mg/L)	(201.2)	(75.5)	(189.2)	(200.3)	(43.6)
Chloride	4545	2995	12340	7433	27
(mg/L)	(7272)	(4114)	(8322)	(7420)	(33)
Chromium (total)	0.006	0.005	0.006	0.005	0.005
(mg/L)	(0.003)	nd	(0.002)	nd	nd
Copper	0.031	0.025	0.04	0.025	0.025
(mg/L)	(0.035)	nd	(0.03)	nd	nd
Iron	1.12	0.058	0.77	2.06	0.36
(mg/L)	(1.76)	(0.08)	(0.99)	(3.24)	(0.59)
Lead	0.004	0.0025	0.009	0.004	0.0025
(mg/L)	(0.005)	nd	(0.10)	(0.003)	nd
Magnesium	307.4	201.1	847.6	1036.7	2.2
(mg/L)	(493.8)	(267.6)	(571.1)	(845.6)	(2.6)

TABLE 2. Extended.

Dune-swale intermediate	Dune-swale deep	West shallow	West intermediate	West deep	Marsh shallow	Marsh intermediate	Marsh deep
4	3	7	5	3	7	5	2
0.03	0.03	0.051	0.03	0.03	0.03	0.03	0.03
nd	nd	(0.048)	nd	nd	nd	nd	nd
0.026	0.027	0.048	0.025	0.025	0.025	0.025	0.025
nd	nd	(0.044)	nd	nd	nd	nd	nd
0.053	0.053	0.067	0.05	0.05	0.05	0.05	0.05
nd	nd	(0.045)	nd	nd	nd	nd	nd
0.026	0.027	0.036	0.025	0.025	0.025	0.025	0.025
nd	nd	(0.028)	nd	nd	nd	nd	nd
0.026	0.027	0.046	0.025	0.025	0.025	0.025	0.025
nd	nd	(0.055)	nd	nd	nd	nd	nd
0.053	0.053	0.14	0.05	0.05	0.05	0.05	0.05
nd	nd	(0.23)	nd	nd	nd	nd	nd
0.026	0.027	0.034	0.025	0.025	0.025	0.025	0.025
nd	nd	(0.025)	nd	nd	nd	nd	nd
0.117	0.049	0.143	0.057	0.033	0.44	0.15	0.066
(0.136)	(0.041)	(0.175)	(0.054)	(0.014)	(0.50)	(0.08)	(0.020)
0.0025	0.0053	0.0025	0.0025	0.0025	0.0038	0.0045	0.0025
nd	(0.0049)	nd	nd	nd	(0.0025)	nd	nd
0.005	0.005	0.006	0.008	0.005	0.025	0.005	0.005
nd	nd	(0.002)	(0.007)	nd	(0.029)	nd	nd
0.05	0.05	0.05	0.05	0.05	0.11	0.06	0.05
nd	nd	nd	nd	nd	(0.13)	(0.03)	nd
0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
nd	nd	nd	nd	nd	nd	nd	nd
0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
nd	nd	nd	nd	nd	nd	nd	nd
97.6	254.0	144.3	192.0	246.7	262.7	594.0	620.0
(74.4)	(265.7)	(51.3)	(47.6)	(73.7)	(238.9)	(98.4)	(70.7)
102	3707	404	1099	1127	4251	14860	14800
(139)	(6316)	(669)	(618)	(1016)	(3293)	(11870)	(15839)
0.005	0.005	0.005	0.005	0.005	0.009	0.005	0.005
nd	nd	nd	nd	nd	(0.007)	nd	nd
0.025	0.025	0.025	0.025	0.110	0.022	0.028	0.025
nd	nd	nd	nd	(0.147)	(0.006)	(0.006)	nd
1.28	1.21	0.81	1.60	2.00	1.60	2.31	1.21
(0.53)	(1.50)	(0.94)	(0.20)	(0.97)	(3.71)	(2.38)	(1.68)
0.0025	0.0025	0.0025	0.0025	0.011	0.003	0.006	0.0025
nd	nd	nd	nd	(0.015)	(0.001)	(0.005)	nd
10.0	244.9	32.6	73.0	98.7	248.6	796.8	782.5
(13.5)	(420.1)	(31.7)	(19.4)	(28.7)	(211.6)	(734.0)	(1014.7)

TABLE 2. Continued.

Parameter	All groundwater	Dune shallow	Dune intermediate	Dune deep	Dune-swale shallow
Manganese	0.068	0.02	0.075	0.114	0.015
(mg/L)	(0.098)	(0.023)	(0.072)	(0.162)	(0.026)
Nickel	0.006	0.005	0.006	0.007	0.005
(mg/L)	(0.004)	nd	(0.003)	(0.003)	nd
Potassium	89.2	66.0	274.2	316.7	1.1
(mg/L)	(150.6)	(91.3)	(177.6)	(211.3)	(0.6)
Selenium	0.006	0.005	0.01	0.02	0.007
(mg/L)	(0.007)	nd	(0.01)	nd	(0.003)
Silver	0.005	0.005	0.005	0.007	0.005
(mg/L)	(0.007)	nd	nd	(0.003)	nd
Sodium	2670	1510	6720	8167	13.1
(mg/L)	(4011)	(2011)	(4342)	(6526)	(11.9)
Thallium	0.001	0.001	0.001	0.001	0.001
(mg/L)	(0.0005)	nd	nd	nd	nd
Vanadium	0.005	0.005	0.007	0.005	0.005
(mg/L)	(0.002)	nd	(0.004)	nd	nd
Zinc	0.053	0.05	0.05	0.05	0.05
(mg/L)	(0.024)	nd	nd	nd	nd
Other Parameters					
Total Dissolved	8066	5455	21564	22133	156
Solids (mg/L)	(11275)	(6845)	(13441)	(19535)	(86)
Total Organic	18.9	1.8	4.7	11.8	19.1
Carbon (mg/L)	(23.4)	(1.3)	(7.5)	(15.1)	(18.0)
Sample Size (field)	51	6	4	3	6
Hydrogen Ion	8.80E-6	3.49E-8	4.41E-8	7.34E-8	7.40E-5
	(5.46E-5)	(2.46E-8)	(4.27E-8)	(8.35E-8)	(1.55E-4)
pH	5.06	7.46	7.36	7.13	4.13
Dissolved Oxygen	1.82	2.79	1.97	2.88	1.57
(mg/L)	(1.44)	(1.24)	(1.10)	(2.78)	(0.83)
Temperature	25.7	26.8	26.2	26.0	26.7
(C)	(1.3)	(0.8)	(0.6)	(0.3)	(1.1)
Specific Conductivity	10012	6607	24875	22507	267
(μmhos/cm)	(13156)	(7368)	(18001)	(18314)	(171)

proved normality of distribution. Transformed values of Mg, K, Na, TOC, TDS, and conductivity did not differ from normal ($p>0.05$). Although distributions of Al, Ca, Cl, Fe, Mn, and DO still differed from normal, normality plots showed that transformation improved the distributions such that ANOVA could be conducted. ANOVA is robust to modest departures from normality (Zar, 1984).

Two-way ANOVA models were not significant for Al and DO; the significance level for the model ($p = 0.057$) for Fe was marginally above the usual decision point. Interactions were significant for pH. Total organic carbon differed across subaquifers but not depths. Calcium, Cl^-, Mg, Mn, K,

TABLE 2. Continued. Extended.

Dune-swale intermediate	Dune-swale deep	West shallow	West intermediate	West deep	Marsh shallow	Marsh intermediate	Marsh deep
0.022	0.057	0.024	0.046	0.070	0.062	0.284	0.141
(0.02)	(0.08)	(0.095)	(0.019)	(0.007)	(0.079)	(0.146)	(0.112)
0.005	0.005	0.005	0.005	0.015	0.005	0.005	0.005
nd	nd	nd	nd	(0.014)	nd	nd	nd
1.2	31.5	8.1	17.0	13.3	74.8	215.6	239.4
(1.7)	(54.1)	(8.1)	(13.2)	(0.6)	(63.7)	(241.7)	(326.2)
0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
nd	nd	nd	nd	nd	nd	nd	nd
0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
nd	nd	nd	nd	nd	nd	nd	nd
53.6	1875	240	560	883	3121	7360	6650
(59.5)	(3226)	(318)	(399)	(196)	(3030)	(5280)	(7566)
0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
nd	(0.0006)	nd	(0.0005)	nd	(0.0008)	(0.002)	(0.001)
0.005	0.005	0.006	0.005	0.005	0.007	0.005	0.005
nd	nd	(0.002)	nd	nd	(0.003)	nd	nd
0.05	0.05	0.05	0.05	0.11	0.05	0.05	0.05
nd	nd	nd	nd	(0.10)	nd	nd	nd
608	6987	1164	2760	3900	8214	19020	21050
(463)	(11270)	(1298)	(1228)	(1375)	(5227)	(13951)	(22557)
6.5	12.3	31.4	9.2	7.3	51.3	26.4	15.5
(4.1)	(2.5)	(30.0)	(8.9)	(3.5)	(35.5)	(18.9)	(6.4)
4	3	6	4	3	6	4	2
1.25E-7	1.06E-7	1.09E-7	6.16E-8	1.04E-7	2.13E-7	1.55E-7	5.20E-8
(4.91E-8)	(7.97E-8)	(4.29E-8)	(4.93E-8)	(1.38E-9)	(2.62E-7)	(4.00E-8)	(2.89E-8)
6.90	6.97	6.96	7.21	6.98	6.67	6.80	7.28
2.23	3.27	1.00	0.51	1.18	2.21	0.76	1.79
(1.42)	(2.55)	(0.64)	(0.37)	(0.16)	(1.48)	(0.50)	(2.40)
24.8	26.1	25.7	24.1	23.1	26.9	24.9	24.9
(0.5)	(1.4)	(1.1)	(0.9)	(0.2)	(0.5)	(0.2)	(1.8)
872	7037	2242	3715	5770	11897	27210	25955
(620)	(10880)	(2119)	(1482)	(1440)	(7147)	(18546)	(23257)

Na, TDS, conductivity, and temperature differed with subaquifer and depth (Table 3).

The pH of groundwater was circumneutral except in shallow depths of the Dune-Swale subaquifer (Table 2, Fig. 2A). In three of the subaquifers, pH increased with depth, but in the Dune subaquifer it declined slightly (Fig. 2A). Temperature varied slightly between subaquifers and generally declined with depth (Fig. 2B). Iron concentrations generally increased with depth (Fig. 3A) but not consistently so in the Marsh subaquifer. Manganese increased with depth (Fig. 3B); values were higher in the Marsh and Dune subaquifers than the other two. Calcium (Fig. 4A), Mg (Fig. 4B), K (Fig.

TABLE 3. Summary of two-way analysis of variance of selected groundwater parameters. Shown are the significance levels for the overall model, effects due to subaquifer, effects due to depth, and subaquifer × depth interactions. NS = not significant. Chemical parameters were transformed ($\log_{10}$) before analysis to improve normality.

Parameter	Model	Subaquifer	Depth	Interactions (subaquifer × depth)
Aluminum	NS	—	—	—
Calcium	0.02	<0.001	0.006	NS
Chloride	<0.001	<0.001	<0.001	NS
Iron	0.057	0.047	0.029	NS
Magnesium	<0.001	<0.001	0.003	NS
Manganese	0.006	0.002	0.009	NS
Potassium	<0.001	<0.001	0.032	NS
Sodium	<0.001	<0.001	0.003	NS
Total Organic Carbon	<0.001	<0.001	NS	NS
Total Dissolved Solids	<0.001	<0.001	0.001	NS
Specific Conductivity	<0.001	<0.001	0.001	NS
pH	0.001	0.008	NS	0.037
Temperature	<0.001	<0.001	<0.001	NS
Dissolved Oxygen	NS	—	—	—

5A), Na (Fig. 5B), TDS (Fig. 6A), conductivity (Fig. 6B), and Cl^- (Fig. 7A) exhibited similar patterns with the lowest values in shallow depths of the Dune-Swale aquifer, concentrations increasing with depth, and the highest concentrations in the Dune and Marsh subaquifers. Total organic carbon differed (Fig. 7B) with three of the subaquifers having high values at shallow depths; the Dune subaquifer had low concentrations in shallow wells.

The first axis of the PCA (Fig. 8) was most important and accounted for 48.1% of the variance explained. Cations, Cl^-, conductivity, and TDS were weighted highly on this axis and clustered tightly. Sample wells were arrayed along PCA axes (Fig. 9) from shallow, Dune-Swale subaquifer samples on the left to intermediate and deep, Marsh and Dune subaquifer samples to the right corresponding to the gradient in cations, Cl^-, conductivity, and TDS.

DISCUSSION—The baseline data indicate that widespread contamination of the Surficial Aquifer on KSC has not occurred. No organochlorine pesticides, aroclors, or chlorinated herbicides occurred above detection limits. The 25 organochlorine pesticides, six aroclors, and 18 chlorinated herbicides analyzed for included those most likely to have been used in the region and their degradation products. For example, DDT and its degradation products (DDD, DDE) and Dieldrin that were applied for mosquito control in the 1940s–1950s (Provost, 1977; Sykes, 1980). Although pesticide residues or degradation products and chlorinated herbicides occurred in some soils (Schmalzer et al., 2000), those concentrations were low, and migration into

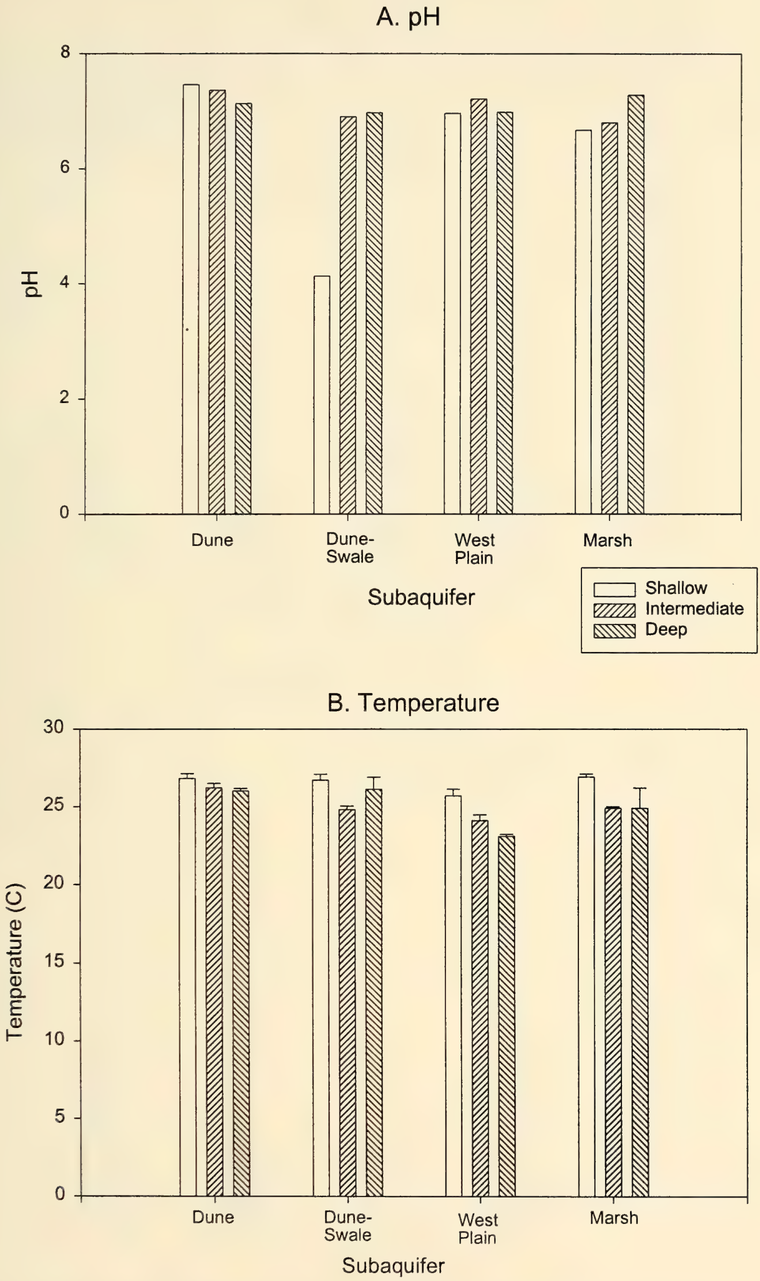


FIG. 2. pH (A) and temperature (B) in groundwater by subaquifer and depth. Depths are shallow = 4.6 m, intermediate = 10.7 m, and deep = 15.2 m. Error bars show standard errors.

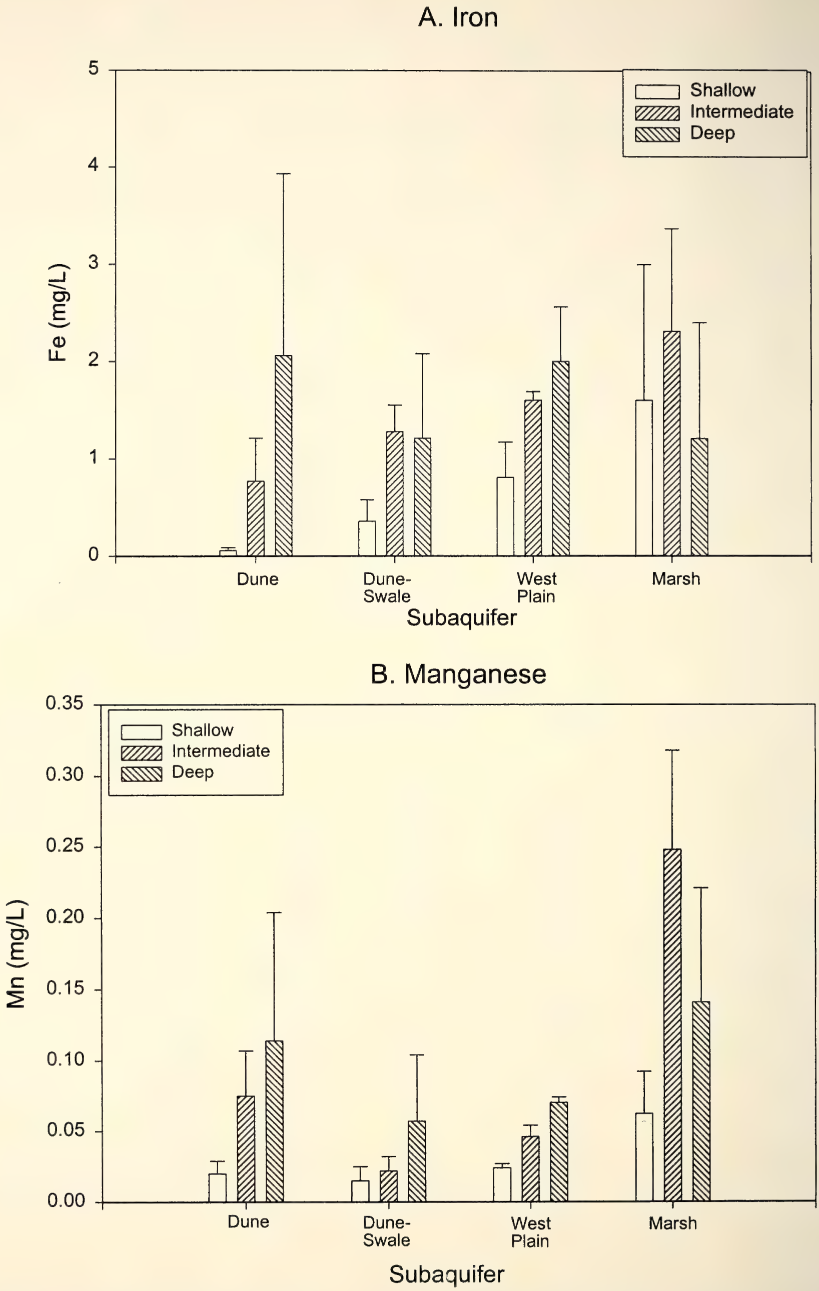
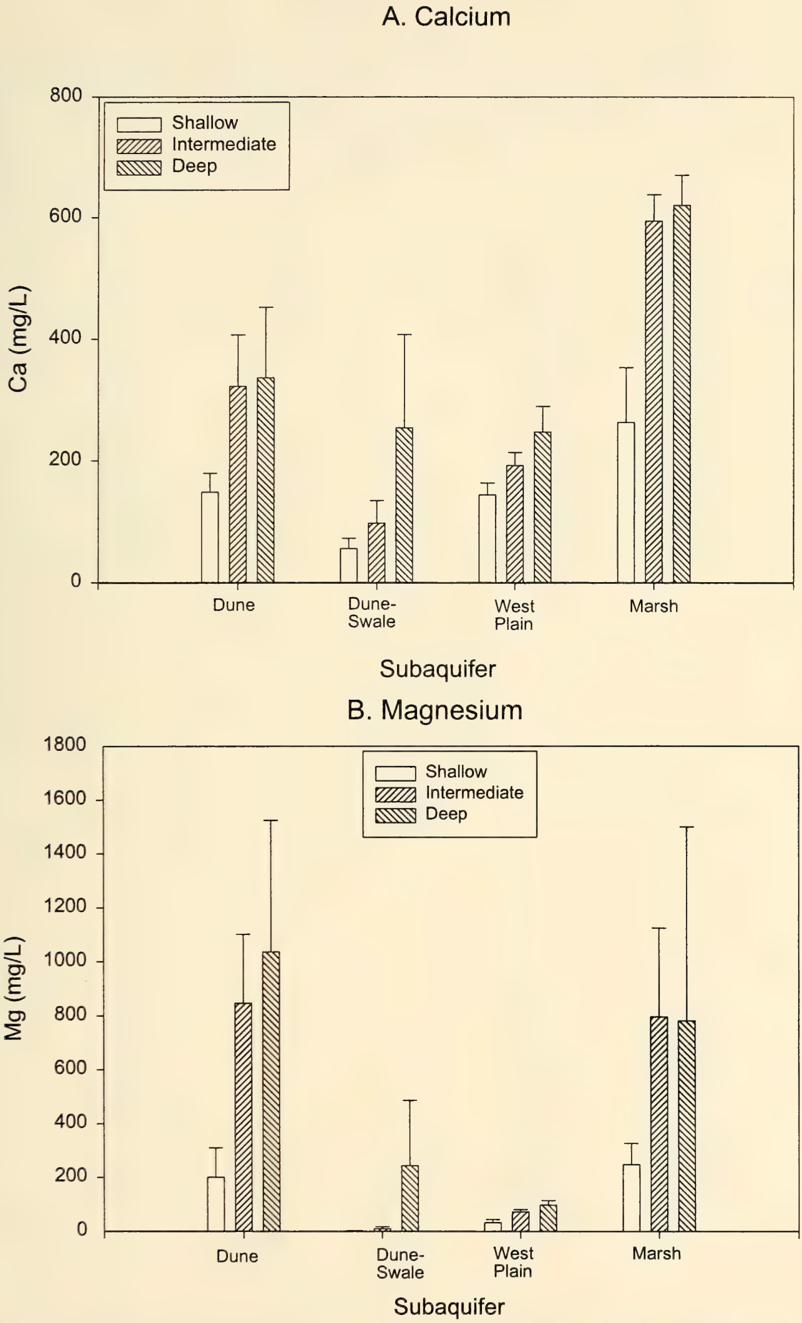


FIG. 3. Iron (A) and manganese (B) in groundwater by subaquifer and depth.



A. Calcium

B. Magnesium

FIG. 4. Calcium (A) and magnesium (B) in groundwater by subaquifer and depth.

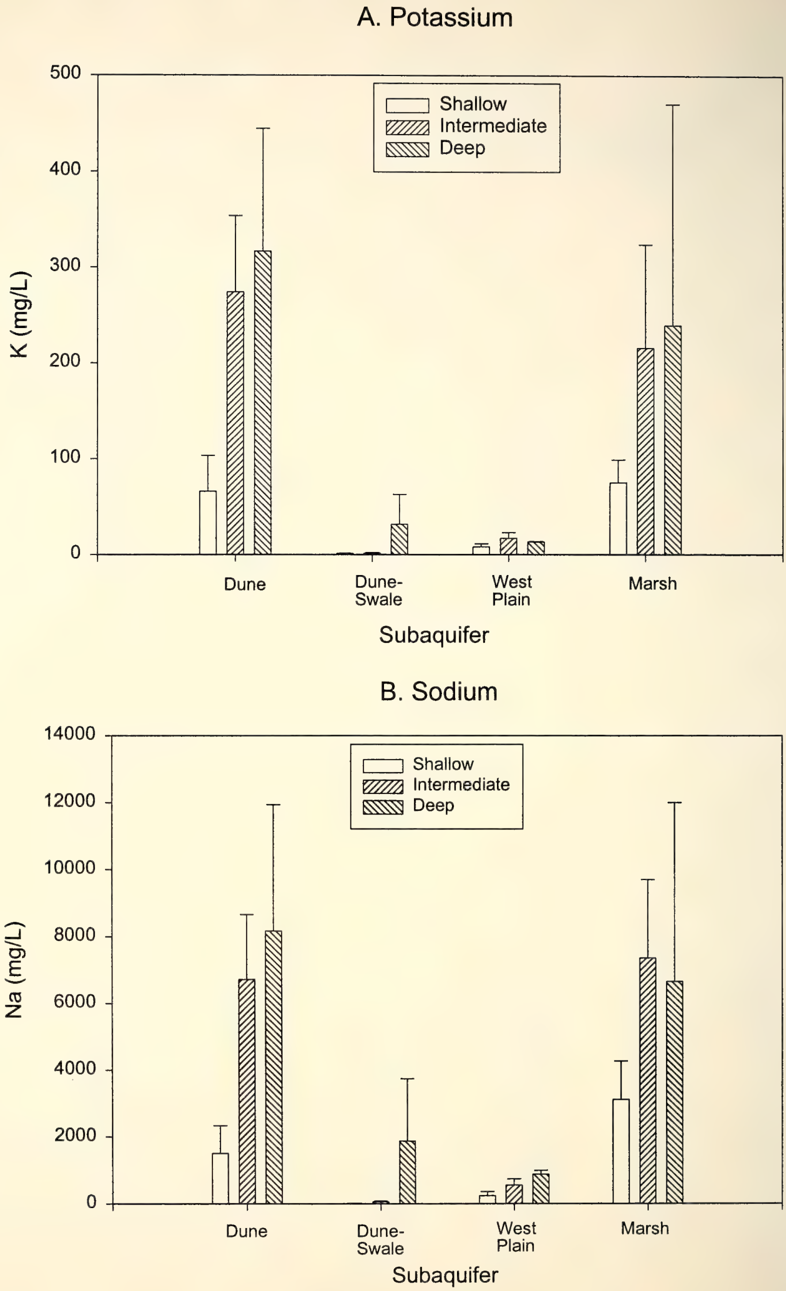


FIG. 5. Potassium (A) and sodium (B) in groundwater by subaquifer and depth.

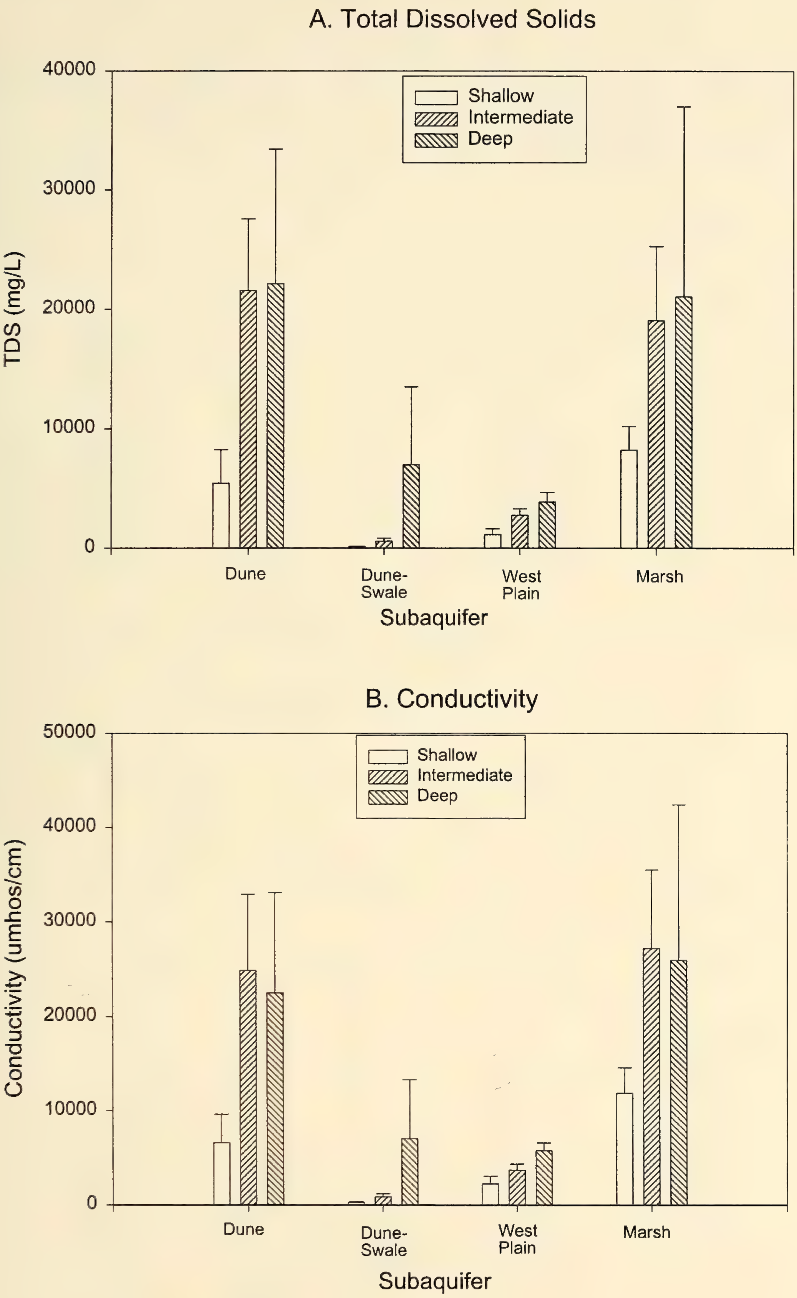


FIG. 6. Total dissolved solids (A) and specific conductivity (B) in groundwater by subaquifer and depth.

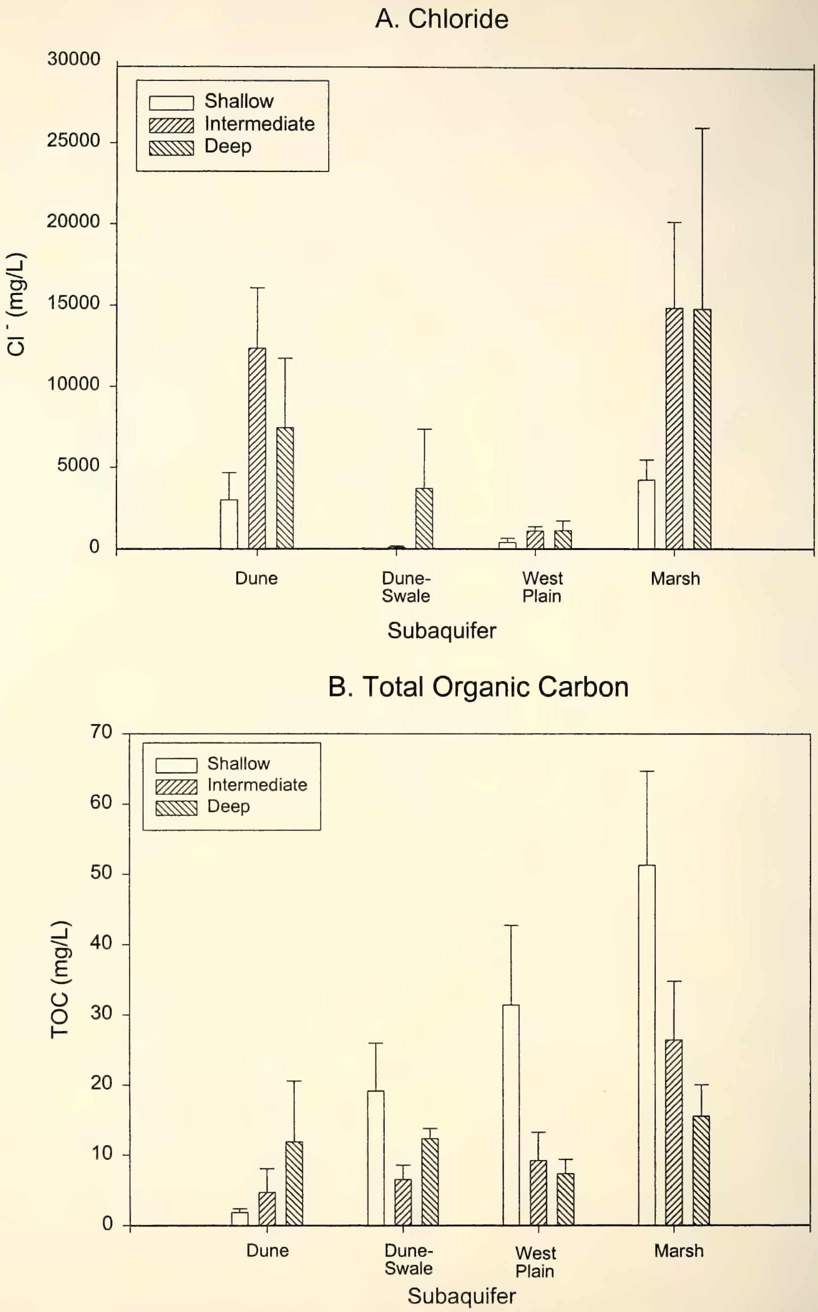


FIG. 7. Chloride (A) and total organic carbon (B) in groundwater by subaquifer and depth.

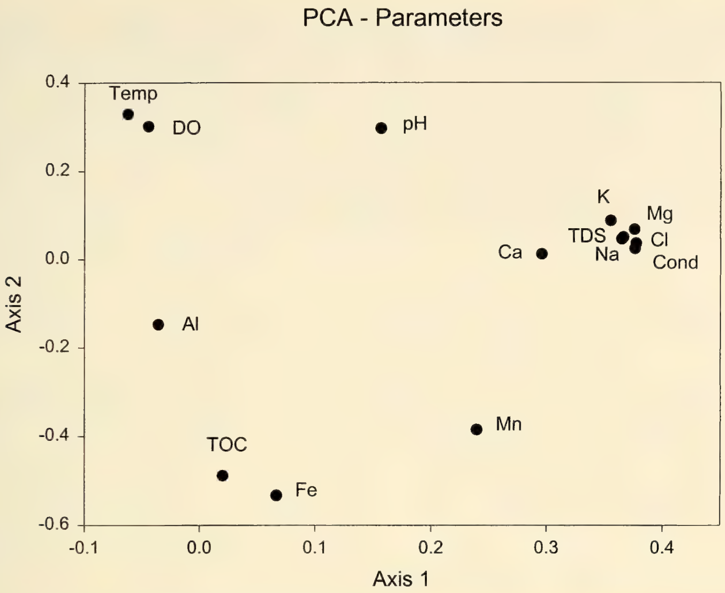


FIG. 8. Principal components analysis of selected groundwater parameters. Shown are the first two axes.

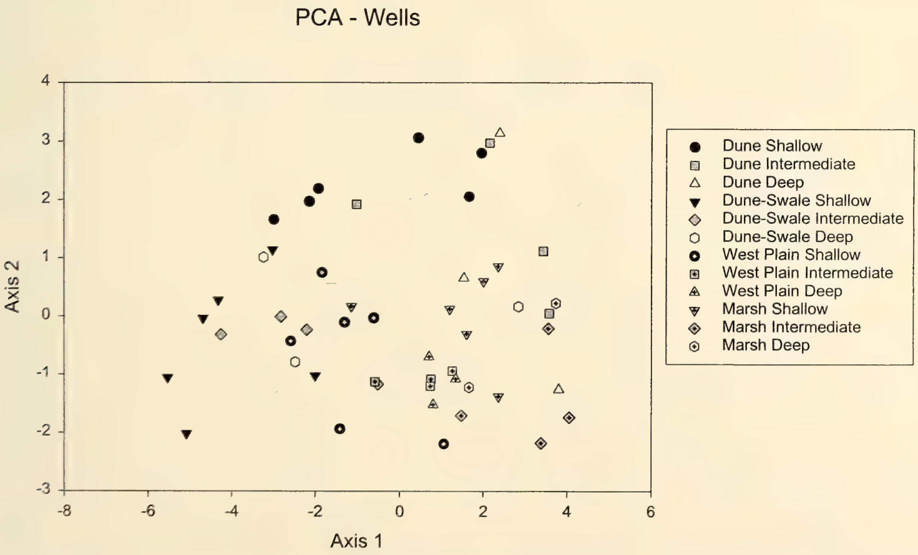


FIG. 9. Scores of groundwater sample wells along first two axes of principal components analysis.

the aquifer either has not occurred or has not been widespread. Clark (1987c) tested background groundwater wells for a smaller number of organochlorine pesticides and chlorinated herbicides including 2,4-D, 2,4,5-TP, Endrin, Lindane, Methoxychlor, and Toxaphene and found none above detection limits. It is possible that other classes of pesticides or herbicides not analyzed for in this study are present in groundwater of KSC.

Some PAHs occurred in the shallow wells. PAHs occur in a variety of KSC soils at relatively low concentrations (Schmalzer et al., 2000). Some occurrence in shallow wells is not surprising. PAHs have both natural and anthropogenic sources (e.g., Suess, 1976; Standley and Simoneit, 1987; Jones et al., 1989a, 1989b, 1989c; Bodzek et al., 1998).

Most trace elements were in low concentrations in KSC groundwater if they occurred above detection levels. This is consistent with the low concentrations of most trace metals in KSC soils (Schmalzer et al., 2001) and the primarily quartz composition of the terrigenous deposits comprising the surficial sediments of Merritt Island (Brown et al., 1962; Milliman, 1972; Field and Duane, 1974). Arsenic, which was most frequently above detection in the Dune subaquifer, was also more abundant in coastal soils (Schmalzer et al., 2001). Al, Fe, and Mn occurred above detection limits more frequently than other trace elements. Al and Fe are abundant crustal components (Kabata-Pendias and Pendias, 1984) and are present in KSC soils (Schmalzer et al., 2001). Intense leaching, particularly in acid scrub and flatwoods soils, mobilizes Al and Fe (Paton et al., 1995). Iron is a typical constituent of groundwater in the Surficial Aquifer in Florida (Miller, 1997). Mn is one of the most abundant trace elements (Kabata-Pendias and Pendias, 1984); it is present in KSC soils, but the concentrations are relatively low (Schmalzer et al., 2001). Solution and precipitation of Fe and Mn are affected by pH and oxidation-reduction conditions.

Total organic carbon is higher in the shallow groundwater wells except in the Dune subaquifer. It is probably derived from soil organic matter present in surface soils and would be expected then to be higher in the shallow wells. Young soils of the Dune subaquifer have little soil organic matter (Huckle et al., 1974), which may account for the low levels of TOC in shallow wells of this subaquifer.

The chemical parameters that vary most with subaquifer and depth are Ca, Cl^-, Mg, K, and Na, and conductivity and TDS that are related to these cations and anions. The trends were generally consistent among these; the shallow wells in the Dune-Swale subaquifer had the lowest values. Concentrations increased with depth within a subaquifer. At a given depth, concentrations in the Dune-Swale and West Plain subaquifers were lower than in the Dune and Marsh subaquifers. Analyses with ANOVA and PCA show the same patterns. These trends reflect increased mineralization with depth and differences between the fresh water Dune-Swale and West Plain subaquifers and the more saline Dune and Marsh systems. In the Dune-Swale subaquifer, surface soils are acid and leached of cations (Schmalzer et al., 2001); however, shell material is still present at depths (Universal Engineering Sciences, Inc., 1998). Shallow groundwater in the Dune-Swale subaquifer is therefore acid and low in minerals, but at depth concentrations of cations increase, as does pH. Surface soils of the Dune subaquifer are alkaline due to abundant shell material (Universal Engineering Sciences, Inc., 1998; Schmalzer et al., 2001). The Dune and Marsh subaquifers interact with saline water of the Atlantic Ocean and Indian River Lagoon system, respectively (Clark, 1987c).

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SCALED CHRYSOPHYTES FROM FLORIDA. VII. OBSERVATIONS ON THE FLORA FROM THE SOUTHEAST

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ABSTRACT: *A total of 36 silica-scaled chrysophytes (Chrysophyceae: 4* Chrysosphaerella *spp., 5* Paraphysomonas *spp., and 3* Spiniferomonas *spp.; Synurophyceae: 18* Mallomonas *spp., and 7* Synura *spp.) was recorded from 33 water bodies in nine south-eastern Florida counties using transmission electron microscopy. The number of taxa per location varied from 0 to16. Seven new records for Florida were observed.*

THE WORK OF Wujek and Siver and co-workers has revealed a diverse freshwater silica-scaled chrysophycean algal flora (Siver and Wujek, 1999 and literature therein). For a general introduction to this taxonomic group, the reader is referred to the above citation. Chrysophytes in this paper are considered as scale-bearing Chrysophyceae and Synurophyceae (Andersen, 1987).

This study presents an account of the scale-bearing chrysophytes (Chrysophyceae and Synurophyceae) from the south-east part of Florida (10 counties, 33 samples) using scanning (SEM) and transmission electron microscopy (TEM). Correlates of these organisms with ecological conditions present at the time of sampling is discussed.

MATERIALS AND METHODS—Plankton net (10 or 20 μm mesh) collections were made over the period extending from 3–9 March 2000 (Table 1). Preparations and observations were as previously described (Wujek, 1984; Wujek and Bland, 1988, 1991).

Physiochemical parameters taken in the field were surface water temperature, pH (HACH model 3), and conductivity (Oakton WD-60), with each site specifically located using a global positioning system (Magellan Trailblazer XL). Data analysis included the Pearson Correlation software on Minitab, Version 11.21 for Windows. All species observed were recorded as either being present or absent in each sample (1 or 0 respectively). Using SPSS, Version 10.0 for Windows, binary logistic regression was used with forward selection procedure to identify any relationship between the occurrence of a species and pH, conductivity, and/or temperature. This provided a regression equation for calculating the probability of a species being present or absent based on pH, conductivity, and/or temperature.

RESULTS AND DISCUSSION—A total of 36 taxa were observed (Table 2). Many of the species mentioned in previous papers were observed again. These are only listed by name and locality number (Table 2). Only those taxa not previously reported for Florida are illustrated (Figs. 1–7). The number of taxa observed from any one locality ranged from zero to 16 (Table 1).

Species richness was relatively large considering the elevated water temperatures observed in this study (Table 1). The most frequently observed *Mallomonas* species were *M. caudata* (present in 73% of the samples), *M. pseudocoronata* (67%), and *M. tonsurata* (60%). Frequently occurring taxa in other genera included *Synura petersenii* f. *petersenii* (61%), *S. curtispina* (42%), and *S. spinosa* and *S. uvella* (both 30%), *Paraphysomonas vestita* (58%), and *Spiniferomonas trioralis* (63%). In contrast, seven taxa were encountered at only a single locality: *Mallomonas cristata, M. perenoides, M. punctifera* var. *brasiliensis, Synura echinulata* f. *leptorrhabda, Paraphysomonas bandaiensis, P. butcheri, P. undulata, Chrysosphaerella annulata,* and *Spiniferomonas crucigera.*

The water temperatures ranged from 22 to 29°C (Table 1). Despite its preference for cold water where it has often been observed under the ice in more northern regions (Cronberg and Kristiansen, 1980; Siver, 1991), cells of *M. akrokomos* were common in these elevated water temperatures. The presence of *M. caudata* at these higher temperatures is not surprising as it has a widespread seasonal distribution (Siver, 1991). Another cold water stenotherm, *M. elongata,* was observed in the highest water temperature measured, 29°C (Tables 1, 2). Our observations of *M. pseudocoronata* supports Siver's (1991) conclusion that it has a relatively high weighted mean temperature, 18.1°C in his study. The presence of the eurythermal taxon *M. tonsurata,* in 61% of our samples, while at the high end of its temperature range, is only one degree higher than previously reported (Siver, 1991).

Species occurring within the widest temperature ranges observed, 22 to 29°C, were *Mallomonas caudata, M. pseudocoronata, Synura petersenii* f. *petersenii,* and *S. uvella.* Species occurring within the narrowest temperature ranges were *P. imperforata* (at 26°C only) and *Mallomonas elongata* and *M. matvienkoae* var. *matvienkoae,* 23 to 26°C (Table 1).

The pH ranged from 6.7 to 9.0 with only one site acidic (Table 1). Many of the species observed were in localities where the pH values were ≤8.0. *Mallomonas akrokomos,* typically found to prefer more acidic water (Siver, 1991), was observed from collecting sites with a pH ranging from 7.5 to 8. In contrast, numerous studies support the indication that *M. caudata* is distributed over a wide pH range. Our data also support the concept of *M. elongata* as being pH indifferent with alkaliphilic tendencies (Siver, 1989). Although both pH and conductance have been shown to control the occurrence of *M. portae-ferreae* (Siver and Hamer, 1989), our data showed no correlations with any of these physiochemical parameters (Table 2). *Mallomonas pseudocoronata* is well documented as being alkaliphilic and again our data support this with only one collection from an acid location (Crooked Lake). The ecological data for *M. pseudocratis* are scarce. Ours is only the fourth report of this taxon, originally described from Chile (Dürrschmidt,

TABLE 1. South-east Florida plankton collection sites containing silica-scaled chrysophytes, 3 March to 9 March, 2000.

Sample no.	Location	GPS coordinates	pH	Temp (°C)	Conductivity µS/M	# taxa obs.
3 March	Dade County					
1	Hammack Lake, Fairchild Tropical Garden (FTG)	—	8.5	25	712	0
2	Pandus Lake, FTG	—	8.3	24	852	0
3	Glade Lake, FTG	—	8.1	25	829	0
4	Kendale Lakes	—	8.0	27	359	5
5	Pond, SW 68th at southern end	—	7.9	27.8	465	4
6	Wild Lime Lake	—	7.9	25	469	10
7	Boy Scout Camp Pond, east side of SR 997,	25°55′64N, 0°27′08W	7.5	25	640	16
4 March	Broward County					
8	Canal System	26°10′38N, 80°13′84W	7.9	24	639	7
9	Forest Trace Lake	26°11′25N, 80°14′42W	8.2	26	509	4
	Palm Beach County—4 March					
10	National WL Refuge Road	26°30′02N, 80°12′37W	7.5	25	485	15
11	Okeeheelee Park	26°37′47N, 80°09′75W	8.3	25	174	3
12	Okeeheelee Park	26°39′13N, 80°09′20W	8.0	26	228	9
13	Palm Beach Lakes	26°43′50N, 80°04′62W	9.0	27	154	3
14	Lake Catherine	26°48′91N, 80°05′16W	8.8	25	443	9
15	Loxahatchee River	26°53′23N, 80°10′52W	7.6	23	642	7
6 March	Martin County					
16	Lake Okeechobee, St. Lucie Canal	26°59′10N, 80°37′35W	8.2	24	259	3
17	Canal NW of Lake Okeechobee	26°59′23N, 80°37′11W	8.2	23	670	5
	Okeechobee County					
18	Kissimmee River, old channel	27°14′25N, 80°59′15W	7.6	24	82	14
7 March	Martin County					
19	Banner Lake	27°03′32N, 80°08′55W	7.8	23	143	14
20	Pond, corner SE 128 & SR 708	27°02′59N, 80°11′43W	7.8	22	408	8
	Palm County					
21	PGA Pond	26°50′33N, 80°08′15W	8.1	26	543	12
9 March	Indian River County					

TABLE 1. Continued.

Sample no.	Location	GPS coordinates	pH	Temp (°C)	Conductivity µS/M	# taxa obs.
22	Ft. Drum WL Preserve	27°38′50N, 80°44′56W	8.0	23	388	9
23	Blue Cypress Lake	27°43′66N, 80°46′55W	71	22	171	8
	Osceola County					
24	Lake Kissimmee	27°48′32N, 81°12′18W	8.1	26	149	15
	Polk County					
25	Lake Rosalie	27°54′82N, 81°23′51W	7.8	23	115	11
26	Tiger Lake	27°54′06N, 81°22′58W	7.4	26	126	10
27	Lake Weohyakapka	27°52′93N, 81°25′91W	8.4	29	111	12
28	Lake Aurora	27°52′93N, 81°27′75W	8.4	25	158	7
29	Saddleback Lake	27°53′44N, 81°28′29W	8.1	23	150	4
30	Twin Lakes	27°53′77N, 81°35′48W	7.9	26	139	6
31	Crooked Lake	27°50′11N, 81°34′32W	6.7	26	65	11
	Highlands County					
32	Lake Byrd	27°37′32N, 81°30′89W	7.5	24	250	7
33	Lake Istokpoga	27°25′40N, 81°18′51W	7.7	26	155	14

TABLE 2. List of taxa observed in the south-east Florida collections. Taxa marked with an asterisk are new records for Florida. Italics indicates whole cells also observed. See Table 1 for locations. Where appropriate, logistic regression analysis for species showing the logistic regression equation for predicting presence/absence of each taxon based on physiochemical parameters is indicated C = conductivity, P = pH, T = temperature). Where: Prob(presence) $= 1/(1 + e^{-Z})$, $Z = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n$.

Taxon	Location	r²
Synurophyceae		
Mallomonas		
M. akrokomos Ruttner	5, 6, 7, 8, 10, 12, 14, *19,* 20	
M. caudata Ivanov em.	*5, 6, 7, 8, 9, 10, 12,* 13, *14, 15, 18, 19, 20, 21, 22,* 23, *24, 25, 26,* 27, 30, *31,* 32, *33*	0.159(P)
M. cristata Dürrschmidt	*27*	
M. cyathellata Wujek & Asmund	*7,* 27, 31, *33*	0.275(T)
M. elongata Reverdin	10, 15, *18, 25,* 26, 27, *31,* 32, 33	0.308(P)
M. guttata Wujek	6, 7, *18,* 19, 22, *24,* 27	
M. mangofera Harris & Bradley	6, *20,* 21	
M. matvienkoae var. *matvienkoae* (Matvienko) Asmund & Kristiansen	8, *10, 19, 22,* 23, 24	
**M. matvienkoae* var. *grandis* Dürrschmidt & Cronberg	10, 18	
M. papillosa Harris & Bradley	24, 33	
M. parvula Dürrschmidt	20, 21	
M. peronoides Momeu & Péterfi	10	
M. portae-ferreae Péterfi & Asmund	*6, 7,* 12, 14, *19, 20,* 21, *22,* 31, 32	
**M. pseudocratis* Dürrschmidt	4, *6,* 7, 8, 10, 15	0.258(P, C)
**M. punctifera* Korshikov var. *brasiliensis* Kristiansen & Menezes	26	
M. striata Asmund var. *serrata* Harris & Bradley	4, 6, 7, 11, 17, 18, 19	
M. tonsurata Teiling em. Krieger	4, 10, 11, *14,* 15, 16, 17, *18,* 19, 20, 21, *23, 24, 25,* 26, *27, 29,* 30, 31, *33*	0.194(C)
Synura		
S. curtispina (Petersen & Hansen) Asmund	7, *10,* 15, 22, 23, 24, 25, *26,* 27, 28, *30,* 31, 32, 33	0.262(P)
S. echinulata Korshikov f. *echinulata*	*22, 23, 28,* 31	
**S. echinulata* Korshikov f. *leptorrhabda* Asmund	19	
S. petersenii Korshikov f. *petersenii*	6, 7, *10, 12, 14, 15, 18, 19, 21, 22, 23, 24, 25, 26, 27,* 28, *29, 30, 32, 33*	0.154 (C)
S. petersenii f. *kufferathii* Petersen & Hansen	10, 18, *27, 31,* 33	0.243(P, T)
S. spinosa Korshikov f. *spinosa*	7, 8, 9, 12, 14, 18, 19, *25, 26, 31*	
S. uvella Ehrenberg em. Korshikov	*7, 19, 20, 21,* 22, 23, *28,* 29, *31, 33*	
Chrysophyceae		
Chrysosphaerella		
**C. annulata* Kristiansen & Tong	21	
C. brevispina Korshikov	*18, 19*	
C. coronacircumspina Wujek & Kristiansen	10, 18, 24, *25*	
**C. septispina* (Nicholls) Kristiansen & Tong	*7, 12,* 16, *19,* 24, *25, 27,* 33	

TABLE 2. Continued.

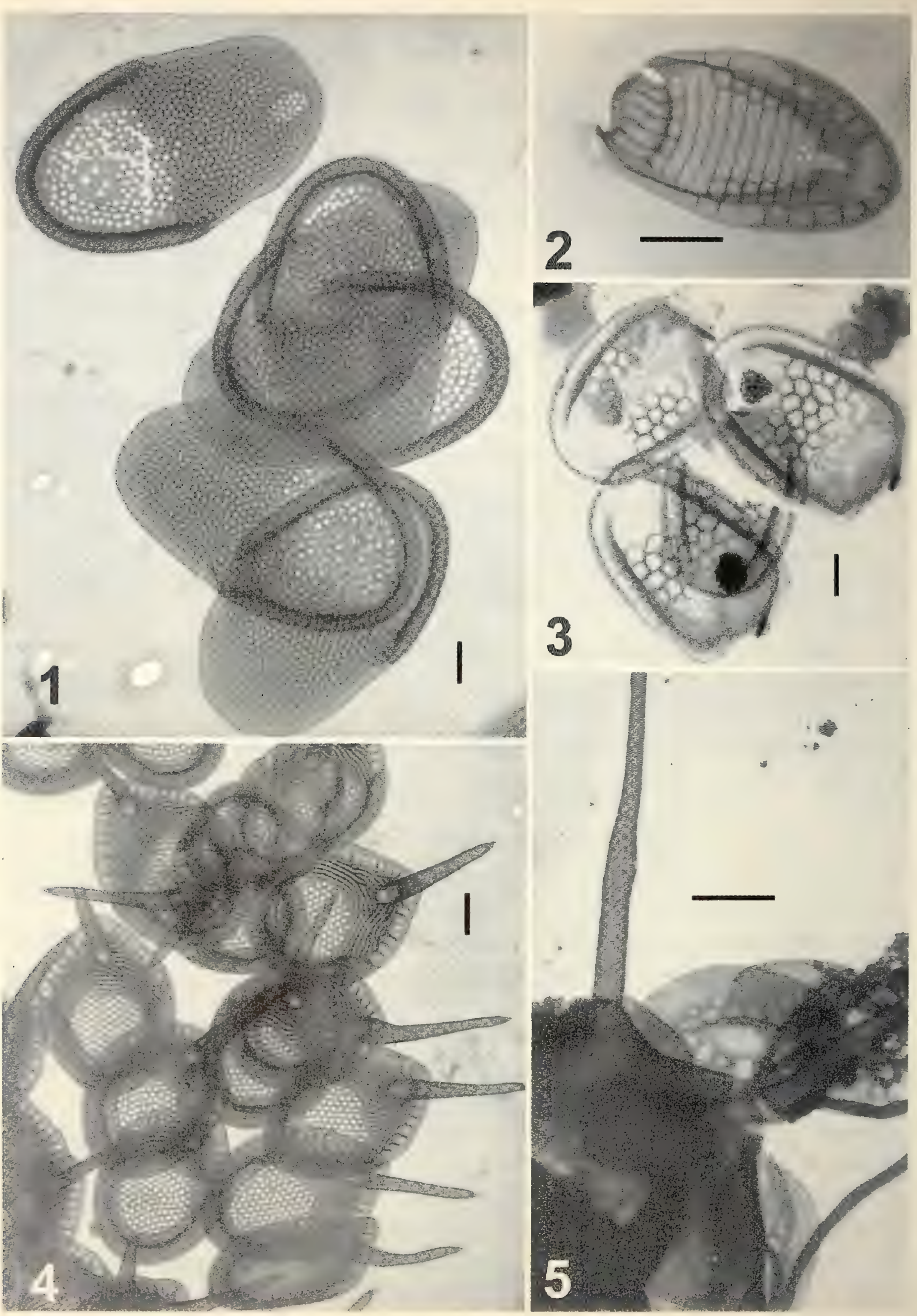
Taxon	Location	r^2
Paraphysomonas		
P. bandaiensis Takahashi	*27*	
P. butcheri Pennick & Clarke	24	
P. imperforata Lucas	26, 30	
P. undulata Preisig & Hibberd	24	
P. vestita (Stokes) de Saedeleer	7, *10,* *12,* 13, 14, *17,* 18, 19, *21,* 22, 23, *24,* 25, 26, *28,* 30, 31, 32, 33	0.178(C)
Spiniferomonas		
S. bourrellyi Takahashi	21, 33	
*_S. crucigera_ Takahashi	7	
S. trioralis Takahashi	4, 5, 6, *7,* *8,* 9, 10, *11,* 12, 14, 17, *18,* 19, 21, *24,* 25, *26,* 27, *28,* 32, 33	

1983), and more recently from Sri Lanka (Dürrschmidt and Cronberg, 1989) and India (Wujek and Saha, 1996). Our study showed it has a very narrow pH range (7.5 to 8.0), and a preference for elevated specific conductances (Tables 1, 2).

Specific conductance ranged from 65 to 852 µS/M (Table 1). The three water bodies at the Fairchild Botanical Garden had the highest conductance and were the only sites in which no scaled chrysophytes were observed. The largest ranges were observed in *Synura petersenii* f. *petersenii, Mallomonas caudata* and *Spiniferomonas trioralis.* The latter taxon was also reported as exhibiting a similar range in Alabama (Wujek and Menapace, 1998) and Texas (Wujek, unpublished). In a Connecticut study, Siver and Hamer (1989) were the first to demonstrate the usefulness of specific conductivity in regulating the distribution of scaled chrysophytes. Siver (1993) later stated that "more studies, including their response to specific ions are needed before a conductivity gradient can be established" for these organisms.

Statistical analysis of the data was completed by running Pearson Correlations and Logistic Regressions to determine the existence and/or strength of the relationship between the presence/absence of a species at each site and the physiochemical factors at that site (Table 2). The accepted confidence level of the p-values for both the correlations and the regressions was 90%, indicated by p-values smaller than 0.05. The computed regression concordance value represents the percent certainty with which one could predict the presence/absence of a particular species based solely upon measurement of the physiochemical factors at a given site in the field.

Logistic regression analysis for nine taxa with physiochemical parameters was greatest with pH (6 taxa), followed by specific conductance (4 taxa) with only two taxa showing a relationship with temperature (Table 2). While a significant relationship was found, low r^2 values (Table 2) indicate that relatively little variation in the presence/absence of a taxon could be ex-



FIGS. 1–3. *Mallomonas.* Fig. 1. *M. matvienkoae* var. *grandis.* Fig. 2. *M. pseudocratis.* Fig. 3. *M. punctifera* var. *brasiliensis.* FIG. 4. *Synura echinulata* f. *leptorrhabda.* FIG. 5. *Chrysosphaerella annulata.* Scale bars = 1 μm

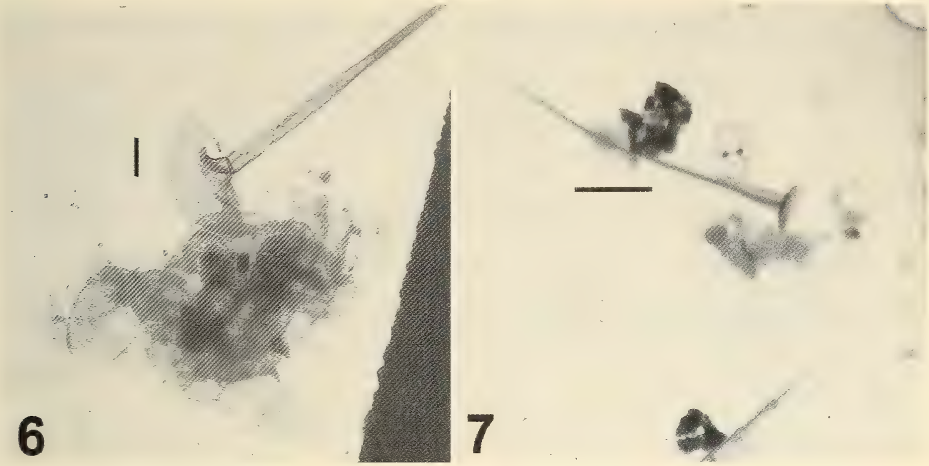


FIG. 6. *Chrysosphaerella septispina.* FIG. 7. *Spiniferomonas crucigera.* Scale bars = 1 μm

plained by pH, specific conductance, and temperature. Of the three physiochemical parameters measured, only pH and temperature correlated significantly with the number of taxa (Pearson Correlation = −0.476, P-Value = 0.005; −0.389, P-Value = 0.025 respectively). No correlation was observed between conductivity to the number of taxa.

In conclusion, as has been demonstrated for other regions in Florida, the south-eastern region contains a diverse silica scaled chrysophyte flora. We believe further collections and observations from other Florida regions will yield additional species. The silica scaled chrysophytes found in Florida based on electron microscopy now comprise 79 taxa.

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ABSTRACT: *Drift fences with funnel traps were used to survey the herpetofauna of sandhill, xeric hammock, and basin marsh habitats at Chinsegut Nature Center, Hernando County, Florida. Xeric upland habitats were trapped for a total of 375 days in 1995–96 and 1998. The second year of the study differed in that animals were marked and pitfall traps were added. We trapped or observed two salamander, 15 anuran, five turtle, one crocodilian, seven lizard, and 17 snake species. Particularly noteworthy captures were four eastern tiger salamanders (*Ambystoma t. tigrinum*), 143 Florida gopher frogs (*Rana capito aesopus*), and one short-tailed snake (*Stilosoma extenuatum*). Recapture rates during the second year of the study ranged from 0% to 13.0% for anuran species and 6.4% to 48.8% for lizard species. Six species were significantly more common in sandhill than in xeric hammock, particularly the six-lined racerunner (*Cnemidophorus s. sexlineatus*), and nine species were more common in xeric hammock than in sandhill. Differences in certain habitat characteristics and proximity to the marsh probably determined the abundance of some species at arrays. Terrestrial arrays nearest the marsh tended to capture more amphibians, many of which were postmetamorphic. During both years, significantly more juveniles than adults were trapped for six anuran species, whereas >70% of all captures of six other anuran species were adults. Five anuran species were more abundant in upland habitats during the first year, when substantially more rain fell, but barking treefrogs (*Hyla gratiosa*) and bullfrogs (*Rana catesbeiana*) were more abundant during the second year. The six-lined racerunner was the only reptile species whose abundance differed between years. Despite past stocking of game fish into May Prairie, fishes had apparently been eliminated by subsequent drought(s), which allowed successful reproduction by amphibian species that typically use small, temporary wetlands. Anurans and reptiles more characteristic of permanent wetlands were also present. Results of this study underscore the importance of xeric hammocks to some species (especially postmetamorphic anurans) and of maintaining fish-free wetlands.*

THE VALUE of xeric upland habitats and their associated wetlands to many rare species in the southeastern Coastal Plain of the U.S. is now widely recognized (e.g., Campbell and Christman, 1982b; Dodd, 1992; Enge and Wood, 1999–2000; Guyer and Bailey, 1993; LaClaire, 1997; LaClaire and Franz, 1990; Moler and Franz, 1987; Mushinsky, 1985; Noss, 1988). These species are threatened by the loss of sandhill or "high pine" (Carr, 1940; Myers, 1990) habitat, which in Florida has declined by 88% since European settlement (Kautz et al., 1993). As of 1987, sandhill habitat covered only

2.4% of the state (Kautz et al., 1993), and only 38.2% of the remaining sandhill habitat is on public lands (Cox et al., 1994).

Historically, high pine savannas were maintained by periodic low-intensity fires ignited by lightning or native Americans. These fires burned the wiregrass, pine straw, and deciduous oaks every 1–15 years (typically 2–5 years), especially in spring and summer (Noss, 1988; Myers, 1990). However, fire-resistant hammocks often form narrow bands of hardwood vegetation along the slope between high pine and lakes or floodplain forests (Platt and Schwartz, 1990).

Although the southeastern U.S. has not experienced the dramatic declines in amphibian populations seen in some parts of the world (e.g., Blaustein and Wake, 1990; Blaustein et al., 1994; Phillips, 1994; Wyman, 1990), destruction, degradation, and fragmentation of terrestrial and wetland habitats have affected the abundance and distribution of amphibian species (Delis et al., 1996; Pechmann and Wilbur, 1994). In Florida, losses of 27% of the total forest area from 1940 to 1980 (Knight and McClure, 1982) and > 50% of all types of presettlement wetlands (Ewel, 1988) have undoubtedly impacted the abundance and distribution of many herpetofaunal species. If changes in abundance and distribution are to be detected, baseline data must be collected on the relative abundance and species composition of present herpetofaunal communities in relatively pristine habitats.

STUDY AREA—Chinsegut Nature Center (CNC) is ca. 5 km NNE of the Brooksville city limits in northeastern Hernando County, Florida (Fig. 1). The 165-ha CNC tract and the 170-ha Big Pine tract collectively comprise the Chinsegut Wildlife and Environmental Area (CWEA) managed by the Florida Fish and Wildlife Conservation Commission (FWC). Drift fences were used to survey the herpetofauna of sandhill, xeric hammock, and basin marsh habitats (see Florida Natural Areas Inventory, 1990) at CNC, which is of particular interest because it is near the range limits of many herpetofaunal species (Auth, 1989; Conant and Collins, 1991). A sandhill community dominated by old-growth longleaf pine (*Pinus palustris*), which is often considered an "endangered" ecosystem (Means and Grow, 1985; Noss, 1988), still exists at CNC. May Prairie, a 22-ha basin marsh, provides suitable breeding habitat for a diverse suite of amphibian species.

The CWEA was once part of Chinsegut National Wildlife Refuge, but ownership of the CNC tract was deeded to the Florida Game and Fresh Water Fish Commission (now the FWC) in 1973 for wildlife management and environmental education purposes. Construction of a nature center on the CNC property was completed in 1986 adjacent to the ruins of a homestead dating from the mid 1800s, when part of the area was farmed. The northern shoreline of May Prairie was planted in bald cypress (*Taxodium distichum*) by the Civilian Conservation Corps in the 1930s to provide nesting habitat for wading birds. Since the 1930s, when the federal government acquired the property, fire may have been excluded for ca. 40 years. The

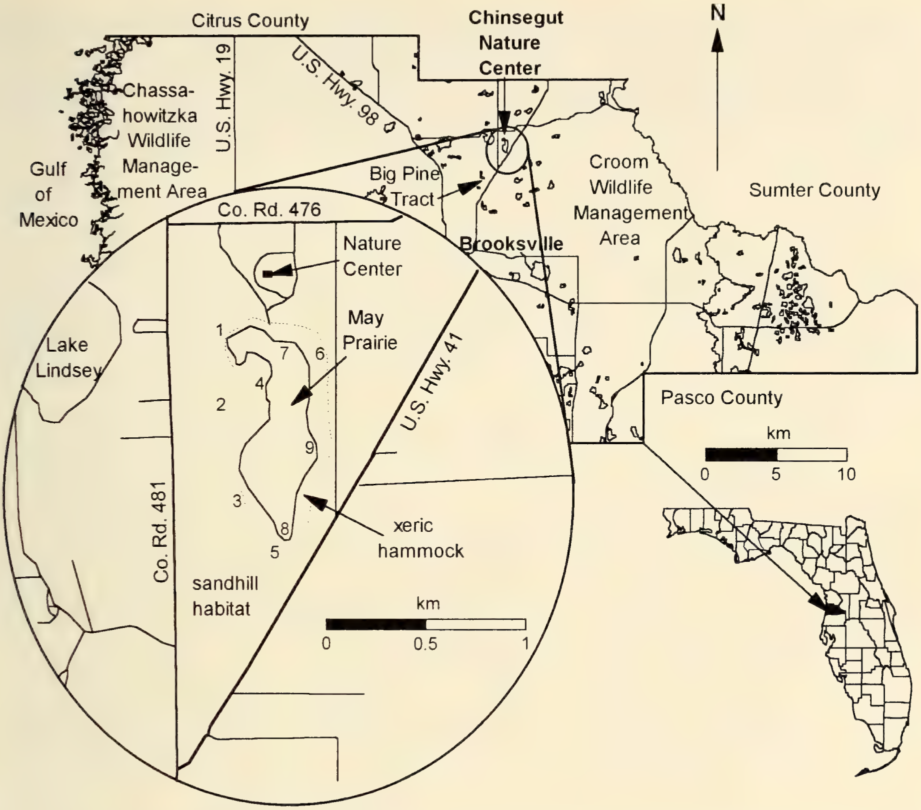

FIG. 1. Map showing the location of Chinsegut Nature Center in Hernando County, FL. Approximate locations of drift-fence arrays are denoted by numbers 1–9 in the inset map.

FWC began prescribed burning at CNC in the 1970s in order to restore the sandhill habitat, although much of the xeric hammock habitat would not burn. Some units were burned at 2- and 3-year intervals, and an average of 24 ha was burned annually from 1982 through 1997 (Florida Game and Fresh Water Fish Commission, 1997).

Soils at CNC consist of a variety of fine sands in the Arrendondo-Sparr-Kendrick Association that are well drained to somewhat poorly drained on 0–5% slopes, and the sands range from 51 cm to > 152 cm deep above loamy material (U.S. Department of Agriculture, 1977). Elevations above mean sea level range from 35 m at the northern end of CNC to 20 m within May Prairie.

May Prairie was probably once a shallow lake but gradually filled with sediments and peat. May Prairie probably burned periodically when sandhill vegetation surrounded the marsh before fire exclusion. These fires restricted shrub invasion, and during droughts, might have burned into the mucky peat and subsequently increased water depths. The acreage and depth of the water in May Prairie are now decreasing due to natural succession, although the decrease may be accelerated by local groundwater consumption and lower annual precipitation. In 1966, the water surface of May Prairie covered 17 ha and the average depth was 1.2–1.5 m, whereas in 1980 the average water depth was 0.3–0.9 m (Florida Game and Fresh Water Fish Commission, 1997).

METHODS—*Habitats*—Habitats were classified using the Florida Natural Areas Inventory's (1990) system. Three drift-fence arrays were installed in each of the three habitat types, and locations of array center points and the adjacent shoreline of May Prairie were mapped using a GPS receiver. Vegetative cover was characterized around each array in April 1996. In the following habitat descriptions, the canopy layer refers to trees > 5 m tall, the shrub layer to woody vegetation 1–5 m high, and ground cover to grasses, sedges, forbs, and woody vegetation < 1 m high.

Arrays 1 (28°37′42.78″N, 82°21′26.20″W) and 2 (28°37′31.30″N, 82°21′25.01″W) were in an 8-ha block of sandhill habitat that had been burned in December 1993, less than 2 years prior to the study, and again in January 1997 during the study (but between the two trapping periods). Array 3 (28°37′16.74″N, 82°21′21.88″W) was in a 9-ha block of sandhill habitat that had been burned in January 1991, over 3 years before the study began, and was burned again on 24 January 1996 during the first trapping period. Array 1 was 55 m from the northwestern corner of May Prairie, whereas Array 2 was 355 m south of Array 1 and 230 m west of May Prairie (Fig. 1). Array 3 was 456 m south of Array 2 and 77 m west of May Prairie. The open canopy around these arrays consisted of large longleaf pines with a subcanopy of various oaks: laurel (*Quercus hemisphaerica*), sand live (*Q. geminata*), turkey (*Q. laevis*), bluejack (*Q. incana*), or sand post (*Q. margaretta*). Shrub cover was sparse and consisted mostly of canopy species, saw palmetto (*Serenoa repens*), and tree sparkleberry (*Vaccinium arboreum*). Wiregrass (*Aristida beyrichiana*) predominated the ground cover, but laurel oak, shiny blueberry (*Vaccinium myrsinites*), and pawpaw (*Asimina reticulata*) were typically present.

Arrays 4–6 were in xeric hammock and had a closed canopy of predominately laurel oaks. Arrays 4 (28°37′34.62″N, 82°21′18.13″W) and 6 (28°37′39.21″N, 82°21′08.24″W) also had large live oaks (*Quercus virginiana*) and longleaf pines in the overstory, whereas Array 5 (28°37′09.74″N, 82°21′15.94″W) had pignut hickory (*Carya glabra*). Shrub cover was denser than around the sandhill arrays and typically consisted of oaks (particularly laurel), saw palmetto, tree sparkleberry, rusty lyonia (*Lyonia ferruginea*), and grapevine (*Vitis* sp.). Grassy and herbaceous ground cover was sparse, but coverage by woody species—oaks, tree sparkleberry, grapevine, and greenbriar (*Smilax* sp.)—was comparable to that around sandhill arrays. Array 4 was 30 m west of May Prairie and 213 m from Array 2. Array 5 was 61 m from the southern end of May Prairie and 269 m from Array 3. Array 6 was 52 m east of May Prairie (Fig. 1).

In xeric hammock habitat nearer May Prairie, large loblolly pines (*Pinus taeda*) replaced longleaf pines, and live and water (*Quercus nigra*) oaks were more common. Saw palmetto often formed dense thickets in xeric hammock habitat along the margin of the marsh, but along open, marshy shorelines where cypress trees were sparse or absent, the shrubs were predominately wax myrtle (*Myrica cerifera*), gallberry (*Ilex glabra*), swamp bay (*Persea palustris*), and dahoon holly (*Ilex cassine*). Dense stands of planted cypress lined the northern one-third of May Prairie and most of the western shoreline. The southern half had a steeper gradient and narrower zone of emergent vegetation—primarily maidencane (*Panicum hemitomon*)—than the northern half, which had dense emergent vegetation wherever cypress was absent. Cypress stands contained little shrub or ground cover. The southern half of the marsh had areas of open water, although most of it contained fragrant water-lilies (*Nymphaea odorata*).

Arrays 7–9 were situated in herbaceous portions of May Prairie (Fig. 1). Array 7 (28°37′39.20″N, 82°21′14.03″W) was at the northern end of the marsh 158 m from Array 6. Array 8 (28°37′11.91″N, 82°21′13.82″W) was only 10 m from the southern edge of the marsh and 89 m from Array 5. Array 9 (28°37′25.15″N, 82°21′08.34″W) was halfway down May

Prairie and 30 m from the shrubby eastern shoreline. Scattered shrubs, primarily buttonbush (*Cephalanthus occidentalis*), were present around arrays in May Prairie, but the predominant vegetation consisted of mats of maidencane and bluestem (*Andropogon* spp.) with lesser amounts of lance-leaf arrowhead (*Sagittaria lancifolia*), smartweed (*Polygonum* sp.), banana lily (*Nymphoides aquatica*), yellow-eyed grass (*Xyris* spp.), pickerelweed (*Pontederia cordata*), pennywort (*Hydrocotyle ranunculoides*), pipeworts (*Eriocaulon* spp.), and water fern (*Azolla caroliniana*). In April 1996, water depths at the center points were 77 cm at Array 7, 33 cm at Array 8, and 58 cm at Array 9.

Trapping—We used an array design that had three 10-m-long arms constructed of 92-cm-wide silt fencing (Enge, 1997) that met at a center point at 120° angles. Each array had a single-opening funnel trap (86 cm long, 25 cm in diameter) at the distal end of the fence on each side and a double-opening funnel trap (86 cm long, 20 cm in diameter) on each side of the fence near the midpoint. Funnel traps were constructed of aluminum window screen, and each array had six single-opening and six double-opening funnel traps. During the second year of the study, a 19-liter plastic bucket was sunk along each terrestrial fence between the single- and double-opening funnel traps such that the fence bisected the pitfall trap through a slit cut in the top.

Traps were shaded with 41-cm-square masonite boards and provided with moistened sponges or towels to minimize desiccation of animals. Shade covers were propped at ca. 45° angles over pitfall and double-opening funnel traps, and laid on top of the closed end of single-opening funnel traps. Trapped animals were typically released ca. 3 m away on the opposite side of the fence. Trapped animals were not marked during the first year of the study, but all except small snakes and hatchling turtles were marked during the second year of the study by clipping toes, clipping ventral scales, or notching marginal scutes.

Trapping was conducted intermittently in sandhill and xeric hammock habitats for a total of 189 days in 1995–96 and 186 days in 1998. The first five trapping periods were 28 August–29 September 1995, 31 October–1 December 1995, 8 January–10 February 1996, 8 March–9 April 1996, and 13 May–13 July 1996. The five trapping periods in 1998 were 3 February–6 March, 3 April–5 May, 2 June–3 July, 3 August–3 September, and 3 October–3 December. Arrays were installed in May Prairie during extremely dry conditions that did not return during the course of the study. Because of high trapping mortality associated with flooded traps, we terminated sampling of May Prairie after the first 32 days of trapping in 1995.

In 1995–96, traps were checked an average of every 3.5 days in August and September; every 4.5 days in November, March, and April; every 7 days in January and February; and every 3 days from May through July. Traps were checked more frequently in 1998 because less frequent precipitation increased the likelihood of trapped amphibians dying from desiccation. In 1998, traps were checked an average of every 2.5 days from February through May and in October and November, and almost daily from June through September. We tried to check traps soon after periods of high precipitation, when we anticipated captures of large numbers of amphibians. In this area of Florida, 52% of the total annual rainfall of 142 cm occurs from June through September (i.e., the wet season) in the form of localized thunderstorms; droughts are most common in spring and fall months. Precipitation was recorded using a rain gauge.

Statistical analysis—When comparing capture data between years, we considered the two sampling periods to be of equal duration, despite three fewer days of trapping in 1998. Chi Square goodness of fit tests (χ^2 at $P \leq 0.01$) were used to calculate differences between expected and observed capture frequencies of species between years or habitat types. Differences between years in capture frequencies of adults and juveniles of various anuran species were calculated using Chi Square analyses (χ^2 at $P \leq 0.01$) of 2×2 contingency tables. Spearman rank correlation (r_s) was used to test for correlations between amphibian captures at terrestrial arrays and the distance these arrays were from water.

Species composition between habitats at CNC and Chassahowitzka Wildlife Management

Area (WMA) was compared using the Jaccard similarity coefficient: $C_J = c/(a + b - c)$, where c = the number of species shared by both habitats, a = the number of species in Habitat A, and b = the number of species in Habitat B (Magurran, 1988).

RESULTS AND DISCUSSION—*Species inventory and notable species*—Comparative data are provided by drift-fence surveys in xeric upland habitats along the Brooksville Ridge, Hernando County, at Chassahowitzka (Enge and Wood, 1999–2000) and Croom (Wood, 2000) WMAs (see Fig. 1 for locations). Overall, we documented 17 species of amphibians and 30 species of reptiles at CNC, including introduced brown anoles (*Anolis sagrei*), which live near the buildings. Drift-fence arrays in xeric uplands at CNC captured 16 amphibian and 22 reptile species (see Table 1 for scientific names). Over a period of five years, we also observed one nesting Florida redbelly turtle (*Pseudemys nelsoni*), two Florida box turtles (*Terrapene carolina bauri*), numerous gopher tortoises (*Gopherus polyphemus*), and one peninsula mole skink (*Eumeces egregius onocrepis*) in xeric uplands, but we failed to trap these species. Four additional species were detected during 32 days of trapping in May Prairie: narrow-striped dwarf siren (*Pseudobranchus a. axanthus*; n = 40), Florida water snake (*Nerodia fasciata pictiventris*; n = 11), Florida green water snake (*N. floridana*; n = 13), and striped crayfish snake (*Regina alleni*; n = 5). An alligator (*Alligator mississippiensis*) was trapped in September 1999 while traps were briefly opened along one arm of an array in May Prairie.

Sampling was insufficient in May Prairie to compile a comprehensive species list for basin marsh habitat, but the semiaquatic and aquatic anuran, turtle, and snake species trapped in the surrounding uplands undoubtedly originated and occurred at much higher densities in May Prairie. Additional trapping in May Prairie would undoubtedly have yielded additional species of aquatic salamanders, turtles, and possibly snakes. The distance of May Prairie from the nearest wetland, and the intervening elevations involved, might limit the presence of sirens (*Siren* spp.) and two-toed amphiumas (*Amphiuma means*) (Snodgrass et al., 1999).

Four adult eastern tiger salamanders captured in xeric uplands at CNC represent their southernmost record for Florida (Travis, 1992). Tiger salamanders were trapped at an array in xeric hammock on 23 January (UF 109401) and 28 May 1996, and at another xeric hammock array and a sandhill array 230 m from May Prairie on 3 February 1996. Tiger salamanders require fish-free breeding ponds with long hydroperiods for successful juvenile recruitment (Semlitsch et al., 1996; Travis, 1992)

Trapping data collected on Florida gopher frogs is of particular interest because it is a state-listed species of special concern (Florida Fish and Wildlife Conservation Commission, 1999). The gopher frog is an explosive breeder that can breed during any time of the year following heavy rains, but most reproduction in Florida occurs from December through April (Franz and Smith, 1999; Palis, 1998), although central and southern Florida populations often breed in summer (Godley, 1992). We could not determine when reproduction occurred, but large numbers of juvenile gopher frogs were captured dispersing from May Prairie in June and July of both years, about one month later than dispersal recorded at Chassahowitzka WMA (Enge and Wood, 1999–2000). Sixty-five juveniles were trapped in 1996 from 1 June through 10 July. Similar results were found in 1998, when 61 juvenile frogs were trapped from 10 June through 3 July. Juveniles had snout-vent lengths (SVL) ranging from 35 to 43 mm and tended to be slightly larger than recent postmetamorphs (31–38 mm SVL) reported by Palis (1998). There were no significant differences between years in numbers of captures or the proportion of adults versus juveniles captured.

A juvenile (280 mm SVL) short-tailed snake captured in sandhill habitat on 5 June 1998 represents only the second record for the species from Hernando County. The first specimen had been captured in 1938 in xeric hammock habitat 11 km north of Brooksville (Van Duyn, 1939).

Sampling efficiency—During the first month of trapping (August–September 1995), 63.6% of the 33 herpetofaunal species eventually trapped in xeric hammock were recorded, and 64.7% of the 34 species in sandhill were recorded. If only the first year of data from CNC is considered, 72.4% of 29 species in xeric hammock and 73.3% of 30 species in sandhill were detected during the first month of trapping. These results were similar to those at Chassahowitzka WMA (Enge and Wood, 1999–2000), where an average of 67.7% of the total species captured in each of the ten habitats sampled was recorded during the first month of trapping (July–August). Only 0–2 new species were detected per habitat during the next three sampling periods at CNC. During the last sampling period in 1996 (May–July), however, five new species were detected in each habitat. During the ninth month of sampling (June 1998), three new snake species were detected in xeric hammock and one new snake species in sandhill habitat.

The warmest period of the year (May–September) was most productive for catching a diversity of species, and no species was trapped only during the coldest period of the year (November–February). Trapping during the winter at Chassahowitzka WMA also detected no unique species (Enge and Wood, 1999–2000). Many winter-breeding amphibian species do not range as far south as Hernando County (Means and Simberloff, 1987), and winter-breeding Florida chorus frogs (*Pseudacris nigrita verrucosa*) were not detected at either CNC or Chassahowitzka WMA, but they were heard calling 1 km away in the Big Pine tract (Fig. 1).

Multi-year drift-fence studies are needed to detect all of the species present in an area because some species occur at low population densities, and weather affects the activity patterns and reproduction of some species. For example, during five years of year-round sampling around a 0.16-ha temporary pond in xeric uplands at Ordway Preserve in Putnam County, Florida, only 62–88% of the amphibian species and 65–81% of the reptile

TABLE 1. Captures from three drift-fence arrays per habitat at Chinsegut Nature Center, Hernando County, Florida, operated intermittently for 189 days from 28 August 1995–13 July 1996 and for 186 days from 3 February–3 December 1998. Captures from pitfall traps in 1998 appear in parentheses.

	Sandhill		Xeric hammock		
Taxon	1995–96	1998	1995–96	1998	Total
Amphibians					
Florida cricket frog (*Acris gryllus dorsalis*)	34	25 (0)	71	127 (2)	259
Eastern tiger salamander (*Ambystoma t. tigrinum*)	1	0	3	0	4
Oak toad (*Bufo quercicus*)	17	2 (1)	1	0	21
Southern toad (*B. terrestris*)	86	15 (11)	117	43 (8)	280
Greenhouse frog (*Eleutherodactylus planirostris*)	67	19 (0)	150	39 (0)	275
Eastern narrowmouth toad (*Gastrophryne carolinensis*)	341	71 (20)	829	110 (36)	1407
Green treefrog (*H. cinerea*)	0	0	1	1 (0)	2
Pinewoods treefrog (*H. femoralis*)	55	17 (0)	114	19 (0)	205
Barking treefrog (*H. gratiosa*)	50	154 (9)	118	212 (8)	551
Squirrel treefrog (*H. squirella*)	7	4 (0)	30	4 (0)	45
Little grass frog (*Pseudacris ocularis*)	4	0	59	0	63
Florida gopher frog (*Rana capito aesopus*)	49	40 (8)	25	16 (5)	143
Bullfrog (*R. catesbeiana*)	10	78 (3)	54	107 (45)	297
Pig frog (*R. grylio*)	7	51 (0)	23	15 (6)	102
Southern leopard frog (*R. sphenocephala*)	403	57 (1)	882	64 (1)	1408
Eastern spadefoot (*Scaphiopus h. holbrookii*)	317	78 (35)	269	39 (15)	753
Unidentified anuran	11	2 (0)	16	1 (0)	30
No. captures	1459	613 (88)	2762	797 (126)	5845
No. species	15	13	16	14	16
Reptiles					
Green anole (*Anolis carolinensis*)	9	15 (0)	23	17 (0)	64
Florida softshell (*Apalone ferox*)	0	4 (0)	0	0	4
Florida scarlet snake (*Cemophora c. coccinea*)	16	14 (0)	0	2 (0)	32
Six-lined racerunner (*Cnemidophorus s. sexlineatus*)	13	109 (6)	0	0	128
Southern black racer (*Coluber constrictor priapus*)	26	38 (0)	39	18 (1)	122

TABLE 1. Continued.

	Sandhill		Xeric hammock		
Taxon	1995–96	1998	1995–96	1998	Total
Eastern diamondback rattlesnake (*Crotalus adamanteus*)	1	0	0	0	1
Southern ringneck snake (*Diadophis p. punctatus*)	2	0	1	1 (2)	6
Corn snake (*Elaphe g. guttata*)	6	12 (0)	3	0	21
Yellow rat snake (*E. obsoleta quadrivittata*)	1	1 (0)	2	3 (0)	7
Southeastern five-lined skink (*Eumeces inexpectatus*)	38	33 (2)	12	14 (2)	101
Florida mud turtle (*Kinosternon subrubrum steindachneri*)	5	4 (2)	1	3 (0)	15
Eastern coral snake (*Micrurus f. fulvius*)	6	8 (0)	3	4 (0)	21
Peninsula cooter (*Pseudemys floridana peninsularis*)	3	3 (2)	1	0	9
Pine woods snake (*Rhadinaea flavilata*)	1	0	1	0	2
Southern fence lizard (*Sceloporus u. undulatus*)	32	34 (5)	10	1 (1)	83
Ground skink (*Scincella lateralis*)	81	48 (1)	79	64 (1)	274
North Florida swamp snake (*Seminatrix p. pygaea*)	0	0 (1)	0	0 (3)	4
Short-tailed snake (*Stilosoma extenuatum*)	0	0 (1)	0	0	1
Florida brown snake (*Storeria dekayi victa*)	0	0	0	1 (0)	1
Central Florida crowned snake (*Tantilla relicta neilli*)	4	2 (10)	0	3 (4)	23
Peninsula ribbon snake (*Thamnophis sauritus sackenii*)	0	2 (0)	4[1]	10 (1)	17
Eastern garter snake (*T. s. sirtalis*)	0	0	0	1 (0)	1
Unidentified lizard	1	0	0	0	1
No. captures	245	327 (30)	179	142 (15)	938
No. species	16	17	13	15	22

[1] This does not include a litter of 11 ribbon snakes apparently born in a trap.

species known to be present were caught in any one year (Dodd, 1991). In this regard, we recorded the Florida softshell, North Florida swamp snake, short-tailed snake, Florida brown snake, and eastern garter snake in upland habitats the second year of the study but not the first, whereas if the study had been conducted only in 1998, we would not have recorded the tiger salamander, little grass frog, eastern diamondback rattlesnake, and pine woods snake (Table 1).

Continued trapping would probably have detected additional species that were uncommon or not readily captured using these methods. The only species observed but not trapped in xeric uplands were the Florida redbelly turtle, gopher tortoise, box turtle, and mole skink, all of which are under sampled by funnel traps along drift fences because of the large size of adults or their behavior (Enge, 2001; Gibbons and Semlitsch, 1982). Semifossorial or fossorial lizards and snakes, such as mole skinks and crowned snakes (*Tantilla* spp.), tend to be captured more frequently in pitfall than in funnel traps (Enge, 2001; Ford et al., 1991, Greenberg et al., 1994). By adding pitfall traps in 1998, we captured more Central Florida crowned snakes and a short-tailed snake (Table 1), but we failed to capture any mole skinks.

Recapture rates for anurans in 1998 ranged from 0% for pinewoods treefrogs (n = 35) and squirrel treefrogs (n = 8) to 13.0% for gopher frogs (n = 69). Only 4.9% of 326 juvenile barking treefrogs were recaptured, and none of 51 marked adults was recaptured. Treefrogs tend to be under sampled by drift fences because of their climbing abilities (Dodd, 1991; Gibbons and Semlitsch, 1982), but dispersing postmetamorphic treefrogs are more susceptible to capture than adults. Only 20.0% of the pinewoods treefrogs captured were juveniles, however. Only 2.6% of 153 Florida cricket frogs were recaptured, possibly because they are inefficiently captured by drift fences (Enge, 2001) or short lived, but most anuran species had recapture rates ranging from 5.2% to 8.0%.

The only marked snake species recaptured was the southern black racer, of which 5.3% (n = 57) were recaptures. Compared to other reptiles, lizards tend to be recaptured frequently by drift-fence arrays (Enge, 1998; Franz et al., 1995; Mushinsky, 1985). Only 6.4% of 31 green anoles were recaptured, but recapture rates for other species ranged from 24.0% for the southeastern five-lined skink (n = 49) to 48.8% for the southern fence lizard (n = 41). Although green anoles are frequently observed on and near drift fences, they are apparently not trapped in proportion to their abundance (Enge, 2001). No marked turtles were recaptured; captures of the Florida softshell and peninsula cooter were of hatchlings.

Comparisons of abundance between years—Twelve anuran species differed significantly in abundance between 1995–96 and 1998 when captures from both habitats were combined. The southern toad, greenhouse frog, eastern narrowmouth toad, pinewoods treefrog, squirrel treefrog, little grass frog, southern leopard frog, and eastern spadefoot were significantly more abundant in 1995–96 than in 1998, whereas the cricket frog, barking treefrog, bullfrog, and pig frog were more abundant in 1998 than in 1995–96.

During the periods sampled, 930 mm of rain fell in 1995–96 compared to only 490 mm in 1998 (Fig. 2), which might have affected the reproductive success of some amphibian species. During a long-term study at a temporary wetland in South Carolina, more amphibian species were able to successfully breed during years with longer hydroperiods (Semlitsch et al., 1996). Based

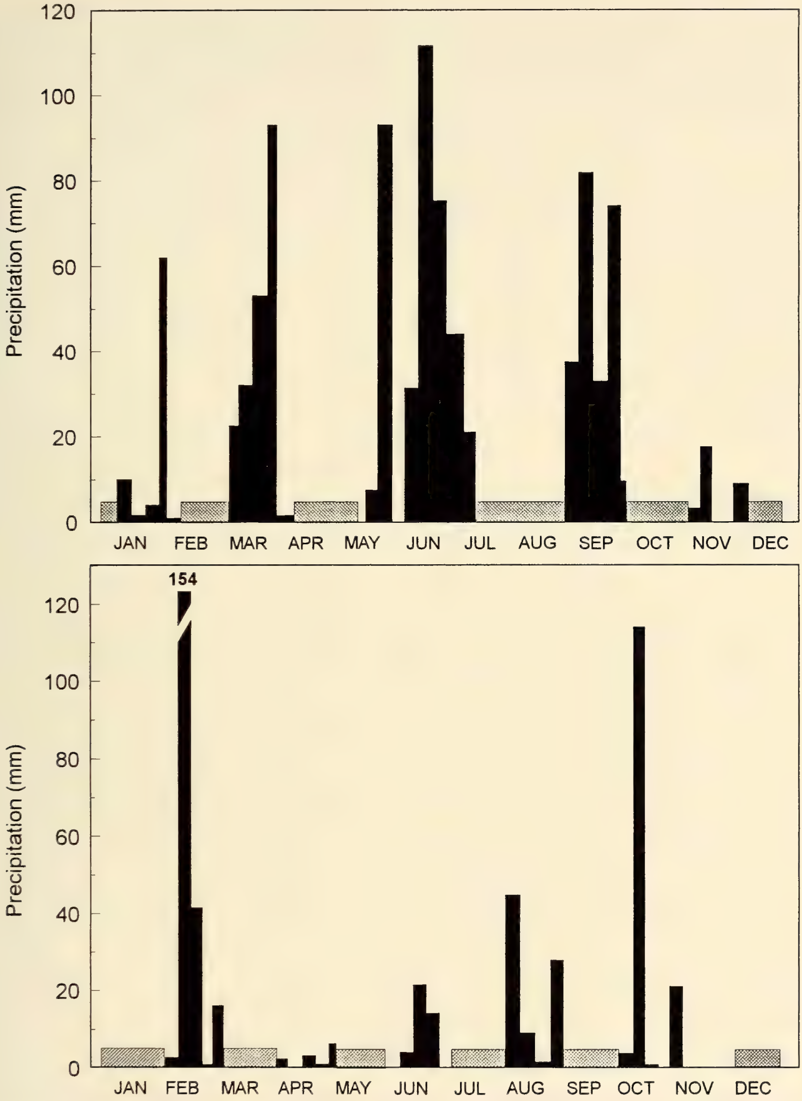

FIG. 2. Precipitation recorded at approximately weekly intervals in 1995–96 (top graph) and 1998 (bottom graph) at Chinsegut Nature Center, Hernando County, Florida. The width of a black bar denotes the duration of the trapping period covered, and gray areas are periods that were not trapped and precipitation not recorded.

on captures of postmetamorphic anurans, reproduction for most species was apparently less successful in 1998 than in 1995–96, except for the barking treefrog and bullfrog, which had proportionally more captures of juveniles than adults in 1998 than in 1995–96 (Table 2). For some reason, cricket frogs, pig frogs, and bullfrogs, which are semiaquatic species, were trapped more frequently in terrestrial habitats in 1998, despite the lower rainfall.

TABLE 2. Percentages of juvenile and adult individuals of the anuran species trapped most frequently in xeric upland habitats at Chinsegut Nature Center, Hernando County, Florida, in 1995–96 and 1998. Differences in age classes between years were compared using Chi Square (χ^2) tests (* indicates significance at $P \leq 0.01$).

	1995–96			1998			
Taxon	n	% juveniles	% adults	n	% juveniles	% adults	χ^2
Florida cricket frog	105	26.7	73.3	154	26.0	74.0	0.0004
Southern toad	203	48.3	51.7	77	27.3	72.7	9.24*
Greenhouse frog	208	29.3	70.7	58	3.4	96.6	15.4*
Eastern narrowmouth toad	1168	6.1	93.9	237	0.4	99.6	11.8*
Pinewoods treefrog	169	24.9	75.1	36	22.2	77.8	0.014
Barking treefrog	168	72.6	27.4	383	84.9	15.1	10.6*
Florida gopher frog	74	90.5	9.5	69	91.3	8.7	0.018
Bullfrog	64	76.6	23.4	233	100.0	0	52.7*
Pig frog	29	89.7	10.3	72	97.2	2.8	1.16
Southern leopard frog	1282	94.1	5.9	123	71.5	28.5	75.2*
Eastern spadefoot	586	95.2	4.8	167	26.3	73.7	380.3*

Proportionally more juvenile than adult southern toads, spadefoots, narrowmouth toads, greenhouse frogs, and leopard frogs were trapped in 1995–96 than in 1998 (Table 2).

Some of the annual differences we observed in anuran captures could be due to different sampling periods that coincided with periods of heavy rainfall (Fig. 2), which are especially important for explosive breeders (e.g., spadefoots, gopher frogs), and with the mass exodus of postmetamorphs. Large numbers of anuran postmetamorphs were trapped from June through September. A total of 1685 anurans was trapped in June 1996, when 527 mm of rain fell, compared to 527 anurans in June 1998, when only 40 mm of rain fell. However, anurans were trapped every day in June 1998, despite rain falling on only four days. Ninety-eight anurans were trapped on 10 June following only 4 mm of rain the preceding day, with most captures being postmetamorphs exiting May Prairie. Anurans tended to move more during periods of heavy precipitation, but postmetamorphs often dispersed from natal sites during periods of little or no rainfall.

Survival of postmetamorphic anurans in surrounding uplands might have been lower in 1998 because of drier conditions. More juvenile than adult barking treefrogs, squirrel treefrogs, gopher frogs, bullfrogs, pig frogs, and leopard frogs were trapped in both years (Table 2). In contrast, > 70% of all captures of cricket frogs, little grass frogs, pinewoods treefrogs, greenhouse frogs, narrowmouth toads, and oak toads were adults (Table 2), which may indicate that these species had less successful reproduction, more rapid maturation rates, or less susceptibility of juveniles to capture. The introduced greenhouse frog requires only moist retreats for reproduction because it undergoes direct development in the egg.

The only differences in reptile captures between years was the greater abundance of six-lined racerunners in 1998 than in 1995–96 ($\chi^2 = 81.3$, 1 df, $P < 0.001$) and of ground skinks in 1995–96 than in 1998 ($\chi^2 = 7.72$, 1 df, $P = 0.005$). The sandhill habitat around arrays 1 and 2 was burned one year prior to the beginning of the 1998 trapping period, and 82 racerunners were caught at these two arrays in 1998 compared to only four in 1995–96. Frequent or recent fire creates more open, sunny conditions and exposed substrates, which are preferred by racerunners (Mushinsky, 1985). Sandhill habitat around Array 3 was burned in January 1996, but only nine racerunners were trapped in 1995–96 compared to 33 in 1998. Although the 1996 fire created favorable habitat for racerunners around Array 3, it probably takes at least one year for animals in adjacent areas to colonize the burn and for resident populations to increase through reproduction. Resident racerunner populations were probably small in 1996 because the area had not been burned for three years.

Comparisons between habitats or sites—Combining both years of trapping data, significantly more cricket frogs, southern toads, greenhouse frogs, narrowmouth toads, pinewoods treefrogs, barking treefrogs, squirrel treefrogs, little grass frogs, bullfrogs, leopard frogs, and peninsula ribbon snakes were trapped in xeric hammock than in sandhill habitat at CNC. The greater abundance of most species of anurans in xeric hammock than in sandhill (Table 1) was probably due partly to more favorable microclimatic conditions, such as more shade, lower temperatures, higher relative humidity, and more leaf-litter. More amphibians were trapped by the sandhill array nearest May Prairie than by two of the xeric hammock arrays, but the habitat around this sandhill array more closely resembled xeric hammock than the habitat around the other two sandhill arrays, which had less canopy cover.

Many amphibian species were probably trapped more frequently in xeric hammock than in sandhill habitat because arrays in xeric hammock tended to be closer to May Prairie ($\bar{X} \pm 1$ SD; 47.7 ± 15.9 m vs. 120.7 ± 95.3 m), although the difference between the two habitat types was not statistically significant (t-test; $t = 1.31$, 4 df, $P = 0.26$). Arrays nearer the marsh, which was the natal site for most amphibian species, would be expected to trap more postmetamorphs than those farther away. The distance of all six terrestrial arrays from May Prairie was negatively correlated with the number of amphibians captured in 1995–96 ($r_s = -0.94$, $P = 0.017$), and the negative correlation was almost significant for 1998 amphibian data ($r_s = -0.77$, $P = 0.058$). In a study in xeric uplands in north-central Florida, however, there was no correlation between the total number of amphibians captured per trap and distance to the nearest body of water, although 83% of amphibians were captured < 600 m from the nearest water (Dodd, 1996).

The abundance and species composition of anurans captured at terrestrial arrays were probably also influenced by the locations of arrays in relation to different portions of May Prairie. We suspect that some portions of the marsh provided hydroperiods, water depths, and vegetative cover that were more conducive to successful larval development and metamorphosis of certain anuran species. Movements of postmetamorphic anurans from May Prairie were probably nonrandom in orientation (see Dodd and Cade, 1998), despite similar surrounding upland habitats. Water depth and the density and structure of vegetation along the extensive shoreline might have influenced dispersal patterns of postmetamorphic anurans.

Gopher frogs, spadefoots, six-lined racerunners, southeastern five-lined skinks, fence lizards, Florida scarlet snakes, and corn snakes were trapped significantly more often in sandhill than in xeric hammock. Some of these species might have been responding to the high insolation, open canopy, and dense ground cover interspersed with areas of bare sand that were present in sandhill habitat. The presence of gopher tortoises in sandhill habitat may have influenced the distribution of gopher frogs, which often use tortoise burrows (Franz et al., 1988).

Species composition of amphibian communities in sandhill and xeric hammock at CNC was almost identical ($C_J = 0.94$), except we failed to trap green treefrogs in sandhill habitat (Table 1). The sampling methodology used in a herpetofaunal survey at Chassahowitzka WMA, where arrays in xeric uplands were also situated near depressional wetlands (Enge and Wood, 1999–2000), was identical to that used at CNC, which allowed comparisons of species composition between sites. The amphibian species composition of xeric uplands at CNC was similar ($C_J = 0.80$ for sandhill and $C_J = 0.81$ for xeric hammock) to that found at Chassahowitzka WMA, except for the capture of tiger salamanders, green treefrogs, and bullfrogs at CNC.

The species composition of reptile communities in xeric uplands was more variable than for amphibians. Reptile species composition between sandhill and xeric hammock habitats at CNC was more similar ($C_J = 0.73$) than that between CNC and Chassahowitzka WMA in sandhill ($C_J = 0.46$) or xeric hammock ($C_J = 0.54$) habitat. The most obvious difference between reptile communities in sandhill and xeric hammock at CNC was the capture of 128 six-lined racerunners in sandhill but none in xeric hammock (Table 1). Six reptile species were trapped in xeric uplands only at CNC, whereas four species were trapped only at Chassahowitzka WMA. Some of the differences in species composition between sites were due to the capture of species that are rarely found in xeric habitats, such as aquatic turtles and the pine woods snake, or species whose low population densities and large size (i.e, eastern indigo snake [*Drymarchon corais couperi*]) or fossorial behavior (i.e., mole skink and short-tailed snake) limit trapping success.

Comparisons between the herpetofaunal species composition of xeric uplands at CNC and Ordway Preserve (Dodd, 1992; Franz et al., 1995) are confounded because only pitfall traps were used at Ordway Preserve. Because pitfall traps are less effective than funnel traps at catching some species, especially large snakes (Campbell and Christman, 1982a; Enge, 2001; Greenberg et al., 1994), reptile species composition is not comparable between these studies. However, when we combined captures from sandhill and xeric hammock habitats, we found that the amphibian species composition of xeric uplands at CNC was somewhat similar to that of Ordway ($C_J = 0.68$). Three amphibian species trapped at Ordway Preserve were apparently absent from CNC, and vice versa. The most obvious differences between amphibian communities at the two sites were the apparent absence of barking treefrogs and tiger salamanders at Ordway, and the apparent absence of dwarf salamanders (*Eurycea quadridigitata*) and striped newts (*Notophthalmus perstriatus*) at CNC. Ambystomatid salamanders do not occur at Ordway Preserve, but barking treefrogs are present (Moler and Franz, 1987), although none was trapped in pitfall traps. The dwarf salamander could be present at CNC; specimens have been trapped in hydric hammock and basin swamp habitats at Chassahowitzka WMA (Enge and Wood, 1999–2000). There is only one record for the striped newt in Hernando County, which represents the southwestern range limit for the species (Franz and Smith, 1999).

Species trapped in xeric uplands in Hernando County at both Chassahowitzka and Croom (Wood, 2000) WMAs but not at CNC were the mole skink (one was observed, however), eastern slender glass lizard (*Ophisaurus attenuatus longicaudus*), eastern coachwhip (*Masticophis f. flagellum*), Florida pine snake (*Pituophis melanoleucus mugitus*), and dusky pigmy rattlesnake (*Sistrurus miliarius barbouri*). We suspect that the latter three species, which are often present in xeric uplands (see also Dodd and Franz, 1995; U.S. Fish and Wildlife Service, 1980) do not occur at CNC, because they would probably have been observed there over the years. The visibility of some species of large snakes is illustrated by the observation of two indigo snakes in the Big Pine tract and several coachwhips in nearby sandhill tracts, despite limited time spent there by observers. Although only one diamondback rattlesnake was trapped at CNC, four sightings were made there over a five-year period. The size of CNC, which is separated by roads from nearby upland preserves, may be too small to support viable populations of some snake species with large home ranges. Fragmentation of xeric uplands throughout Florida has increasingly isolated and diminished the size of populations of many species, which may have profound genetic implications or result in local population extinctions (Hokit et al., 1999; McCoy and Mushinsky, 1994; Means and Grow, 1985; Noss, 1988; Tiebout and Anderson, 1997).

Importance of May Prairie—The presence of May Prairie at CNC accounted for the existence and/or abundance of many of the species trapped in xeric uplands. The abundance of semiaquatic anuran species—cricket frog, little grass frog, leopard frog, pig frog, and bullfrog—in xeric uplands reflected the proximity of May Prairie. The productivity of May Prairie is reflected in the capture of 165 pig frogs and 169 North Florida swamp snakes during 32 days of trapping in 1995.

May Prairie provided suitable breeding habitat for amphibian species that are typically not encountered together. The array of amphibians present included one salamander and eight anuran species that principally breed in small, isolated wetlands. Most of these species are restricted to breeding in ephemeral wetlands. May Prairie also contained six anuran species—cricket frog, southern toad, green treefrog, pig frog, leopard frog, and narrowmouth toad—that breed in both isolated wetlands and open marshes, but only the first five species commonly breed in permanent marshes (Moler and Franz, 1987).

May Prairie has been stocked with game fish at least twice, with the most recent stocking consisting of largemouth bass (*Micropterus salmoides*) and a variety of sunfish (*Lepomis* spp.) in 1983, the year after the marsh completely dried up except for a few alligator holes. Electroshocking in 1988 indicated that largemouth bass and chubs predominated (Florida Game and Fresh Water Fish Commission, 1997), but subsequent droughts have probably eliminated fish populations. No fishes were trapped in funnel traps or caught during numerous dip-netting surveys.

The absence of fish in May Prairie is presumably important in maintaining a diversity of amphibian species at CNC, because the eggs and larvae of many amphibian species are not adapted to withstand predation by fish (Kats et al., 1988; Moler and Franz, 1987; Wilbur, 1984; Woodward, 1983). These amphibian species typically breed in small ephemeral wetlands, but large basin marshes can provide suitable habitat if fishes are absent. Periodic drying of May Prairie probably benefits amphibian species that lack well developed antipredator defenses, such as unpalatability or avoidance behavior (Kats et al., 1988), by reducing population levels of predaceous invertebrates. Many field studies of tadpole communities emphasize the importance of pond hydroperiod and predation rather than competition in determining species composition (e.g., Skelly, 1997; Wellborn et al., 1996). Anuran species that breed in ephemeral environments must grow rapidly and metamorphose prior to pond drying (Newman, 1989; Wilbur, 1987), which may explain why their tadpoles typically forage actively (Babbitt and Tanner, 1997; Woodward, 1983) and do not avoid predators (Kats et al., 1988).

Some amphibian species might not have successfully bred in May Prairie during past periods when it completely dried up or when it contained fish populations. Some obligate breeders in ephemeral wetlands are relatively long-lived (Blaustein et al., 1994; Gill, 1985), and these species might have been able to persist at low population levels at CNC until introduced fish were eliminated from May Prairie during subsequent droughts. Amphibians dependent on ephemeral breeding ponds sometimes do not successfully reproduce every year (Dodd, 1992; Murphy et al., 1993; Pechmann et al., 1989), but reproductive failures in successive years may result in local population extinctions of some species. The annual variation in amphibian reproductive success is reflected in a drift-fence study at a 0.5-ha temporary wetland in South Carolina, where annual numbers of successfully metamorphosing juvenile amphibians were positively correlated with hydroperiod length, ranging from 0 to >75,000 individuals of 15 species (Pechmann et al., 1989). Estimated annual reproductive failure rates for 13 amphibian species over a 16-year period ranged from 42% to 56% (Semlitsch et al., 1996).

The continued existence at CNC of amphibian species that are obligate breeders in ephemeral wetlands suggests that either fish populations did not survive for long periods in May Prairie or that shallow portions of May Prairie might have served as temporary ponds when they became isolated from the main water body. The northern end of May Prairie has diverse aquatic habitats that provide different water depths, hydroperiods, and patterns of vegetative cover. The numerous arms and shallow shoreline depressions (including a sinkhole) at the northern end of the marsh may have shorter hydroperiods than the main body of the marsh and could provide suitable habitat for the development of eggs and larvae of amphibian species that cannot tolerate fish or large invertebrate predators. Also, the dense vegetative cover in many parts of May Prairie might reduce predation of tadpoles by fish (Diehl, 1988; Werner et al., 1983) and invertebrates (Babbitt, 1996). During the study, however, gopher frogs and barking treefrogs were mostly heard calling from the deeper southern half of the marsh, which suggests that the main body of May Prairie was suitable for ephemeral-wetland breeders. We never heard spadefoots calling, and we believe they bred near the northern part of May Prairie in small swales that briefly contained water after heavy rains. Spadefoot tadpoles are able to survive in extremely ephemeral bodies of water because they are superior competitors, grow rapidly, and metamorphose quickly, although they are highly susceptible to predation (Morin, 1983; Newman, 1989; Wilbur, 1987; Woodward, 1983).

Any herpetofaunal populations that underwent local extinction during unsuitable conditions in May Prairie or surrounding uplands (e.g., during 40 years of fire exclusion) could have recolonized via interdemic migration. Recolonization of habitats by many amphibian species may be compromised by physiological constraints, relatively low mobility, and site fidelity to a particular breeding pond (Blaustein et al., 1994; Duellman and Trueb, 1986; Gill, 1978; Semlitsch, 1998; Sinsch, 1990). Many herpetofaunal species inhabiting xeric uplands in Florida form metapopulations (Dodd, 1994, 1995) that are occasionally able to recolonize unoccupied patches of suitable habitat if they are not too isolated. Some terrestrial amphibians in xeric uplands have been trapped 900–5000 m from the nearest known water source (Dodd, 1996; Franz et al., 1988; Greenberg, 1993). An ephemeral wetland situated ca. 600 m east of May Prairie, or wetlands in the Big Pine tract, may provide alternative breeding sites for obligate temporary pond species. Lake Lindsey, which is ca. 500 m west of May Prairie (Fig. 1), provides permanent water for aquatic species. Recolonization of CNC might be affected by habitat fragmentation, because CNC is situated in a triangle formed by three highways, and May Prairie is the only wetland in this habitat patch (Fig. 1).

Roads may hinder movements and thus effectively isolate populations of some amphibian species (deMaynadier and Hunter, 1998; Fahrig et al., 1995; Gibbs, 1998; Langton, 1989; Mader, 1984).

MANAGEMENT IMPLICATIONS—The xeric hammock surrounding May Prairie was once high pine, as evidenced by the remnant, large longleaf pines. Prolonged absence of fire allowed succession to a hardwood forest, and reversing the process would be difficult. Only a high-intensity fire during drought conditions would now affect the vegetative composition of the xeric hammock, and such a fire would probably not revert the hammock to high pine because of the scarcity of wiregrass.

The presence of hammocks around large wetlands in xeric uplands is probably beneficial in maintaining the wildlife diversity in an area. The extensive canopy in hammocks helps maintain a higher relative humidity, and the accumulation of compacted oak leaves on the forest floor helps retain soil moisture. These conditions may prevent newly metamorphosed amphibians from desiccating when leaving natal sites for surrounding uplands, and these hammocks may even serve as ‘‘grow-out’’ areas for juvenile amphibians. Hammocks also provide more suitable habitat than high pine for foraging or dispersing aquatic and semiaquatic herpetofauna. Xeric hammocks adjacent to wetlands often have the highest abundance and diversity of amphibians (Enge and Wood, 1998, 1999–2000).

Frequent, low-intensity fires that start in high pine communities should be allowed to burn naturally into hammocks, but we believe that wildlife diversity is not promoted by injudiciously girdling and/or herbiciding hardwoods, or by attempting to burn hammocks during drought conditions in an attempt to restore sandhill vegetation. Historically, variability existed among high pine sites, hammocks were often present along slopes above wetlands, and ecotones and transitional communities provided the central habitats of some species (Myers, 1990). Land managers must maintain a variety of habitats and vary the season, frequency, and regularity of fire regimes within and among high pine sites in order to preserve a diversity of plant and animal species (Campbell and Christman, 1982b; Myers, 1990).

Isolated wetlands in xeric uplands are necessary for the successful reproduction of many amphibian species. Amphibian populations have undoubtedly been affected by the 56% decline in Florida’s herbaceous wetlands from 1936 to 1987 (Kautz et al., 1993). Recently, the importance of preserving isolated wetlands as small as 0.2 ha has been stressed, because they are not considered as wetlands under current federal regulations due to their small size or ephemeral nature (Semlitsch and Bodie, 1998). The importance of such small, isolated wetlands for amphibian reproduction and for preserving regional biodiversity has been widely recognized (Dodd, 1992; Semlitsch et al., 1996; Semlitsch and Bodie, 1998), and it has been suggested that larger, more permanent wetlands may be less diverse (Moler and Franz, 1987) because of the existence of predatory fish or invertebrates (Hecnar and M'Closkey, 1997; Morin, 1983; Semlitsch et al., 1996; Skelly, 1997; Wellborn et al., 1996; Wilbur, 1984, 1987; Woodward, 1983). We found that a large, fish-free basin marsh, which contained game fish in the past, can provide suitable breeding habitat for at least 15 species of amphibians. This amphibian species richness is similar to that found around a small temporary pond in xeric uplands in north-central Florida (Dodd, 1992).

Little has been written about the importance of keeping fishes out of isolated wetlands (however, see Christman, 1992; Guyer and Bailey, 1993; Semlitsch, 2000). The ephemeral nature of many wetlands will eliminate introduced fish, and their isolation from other wetlands will prevent natural recolonization by fish. The introduction of predatory fish and the conversion of temporary ponds into an interconnected series of permanent ponds were suggested as being partially responsible for a decline in anuran species richness in an urban development in west-central Florida (Delis et al., 1996). The absence of fish in large wetlands with long hydroperiods or even permanent water may make them suitable breeding sites for amphibians that utilize ephemeral wetlands. Large wetlands are often viewed as unproductive unless they contain fish, but even without fish they can be productive for invertebrates, amphibians, reptiles, wading birds, waterfowl, and mammals. Public-land managers and private landowners need to be educated about the potential value of fish-free wetlands to many wildlife species. Posting informational signs may help keep some wetlands from being stocked by anglers.

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AN ASSESSMENT OF THE "LEAF PACK" TECHNIQUE FOR MEASURING HETEROTROPHIC TURNOVER OF PLANT LITTER APPLIED TO THE ESTUARINE ENVIRONMENT OF SOUTHWEST FLORIDA USING *THALASSIA TESTUDINUM* AND *RHIZOPHORA MANGLE*

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Abstract: *We applied the "leaf pack" technique (e.g., Merritt et al., 1979) that has been successfully used to characterize freshwater ecosystems, worldwide (Cushing et al., 1994), in a pilot study to test its feasibility in an estuarine environment of southwest Florida using* Thalassia testudinum, *and* Rhizophora mangle. *Our purpose was to investigate the utility of the "leaf pack" technique as a suitable means of indicating estuarine ecosystem health in this region. Evidence that weight loss of* Thalassia *leaf packs was substantially influenced by confounding factors were interpreted as indicating an unsuitability of the employed leaf pack procedures for this species, whose blades are both positively buoyant and exceedingly fragile, as a means of reliably characterizing ecosystem health. In contrast,* Rhizophora *leaves appeared to be more practical for use in leaf pack experiments. In certain instances both species experienced a weight-gain phenomenon, in the early stages of processing, which appeared consistent with extensive microbial colonization and growth. Weight gains recorded of certain* Thalassia *leaf packs were consistent with observations of heavy epiphytic growth whose visual appearance was different from that found on* Rhizophora.

Despite recent mandates for many state and federal government agencies in the United States to institute ecosystem management, few direct measures of ecosystem health have been incorporated into management activities. Often data on selected populations are summed to establish ecosystem condition. At the same time estuarine monitoring (and research) often requires indices that are more immediately accessible and informative of ecosystem function in order to document changes in response to stressors.

In south Florida estuaries, turnover of detrital plant material represents a major component of heterotrophic function (Odum and Heald, 1975). While rates of plant detrital litter processing may vary as a function of factors such as plant species, habitat, and season, they appear consistent for a given species within a habitat or region (Zieman et al., 1984). Therefore changes in rates of processing of plant material should indicate alterations in ecosystem function, or stressors such as prolonged periods of high or low salinity, nutrient enrichment and dissolved oxygen depletion.

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A direct measure of ecosystem processes should be achievable by measuring rates of coarse detrital litter turnover (processing) of turtle grass, *Thalassia testudinum,* and red mangrove, *Rhizophora mangle,* two major carbon sources for heterotrophs in estuaries of south Florida. Degradation of these and other vascular plants has been found to be a function of chemical, biological and physical processes, including loss of labile compounds, microbial decomposition, invertebrate ingestion and mechanical fragmentation (Odum et al., 1973; Rublee and Roman, 1982; Klump and Van der Valk, 1984). Organic detritus from both *Thalassia* and *Rhizophora* forms a significant fraction of the available food particles in many local ecosystems (Odum and Heald, 1975). The leaf pack technique was designed to be a direct index of the processing of detrital litter. Peterson and Cummins (1974) pointed out it is not necessarily assumed that weight loss from the leaf packs is identical to heterotrophically processed biomass, however the justification of this technique draws upon weight loss primarily resulting from such processes.

We performed our experiments in Tarpon Bay, a shallow 13 km^2 embayment which is part of the lower Caloosahatchee River Estuary that includes nearby San Carlos Bay and Pine Island Sound in Southwest Florida. Tarpon Bay lies entirely within J.N. 'Ding' Darling National Wildlife Refuge, Sanibel, Florida, and is designated a no-wake zone for powerboats. *Thalassia* is the most ubiquitous seagrass species (Wilzbach et al., 2000) and *Rhizophora* is the dominant riparian fringe species in Tarpon Bay. The bay is fringed with dense *Rhizophora* except at one site containing several buildings on the south shore. *Thalassia* and *Rhizophora* therefore contribute heavily to the detrital mass of Tarpon Bay, and as such, serve as a critical food base for commercially and recreationally harvested fishes and crustaceans. Studies in neighboring south Florida estuaries (Odum et al., 1973; Odum and Heald, 1972) have shown that *Thalassia* beds produce, on average, 1500g organic matter/m^2/yr, and fringing *Rhizophora* stands contribute over 8 metric tons dry weight detritus/ha/yr.

Because it opens to San Carlos Bay at the northeast end (and through a much smaller opening at its northwest end), Tarpon Bay is influenced by fresh water releases from the Caloosahatchee River. The major environmental stressor on the system is likely to be releases of fresh water to the estuary that exceed both the quantities and seasonal periodicities of the natural fluctuations experienced before the installation of Franklin Lock and Dam in the mid-1960s. Degraded water quality, resulting from agricultural and urban runoff in the watershed, is also a major stressor (Wilzbach et al., 2000), and concern exists that the rapidly increasing population of greater Fort Myers will intensify these influences. We undertook the present study to investigate the utility of the "leaf pack" technique as a means of measuring estuarine ecosystem health in this region.

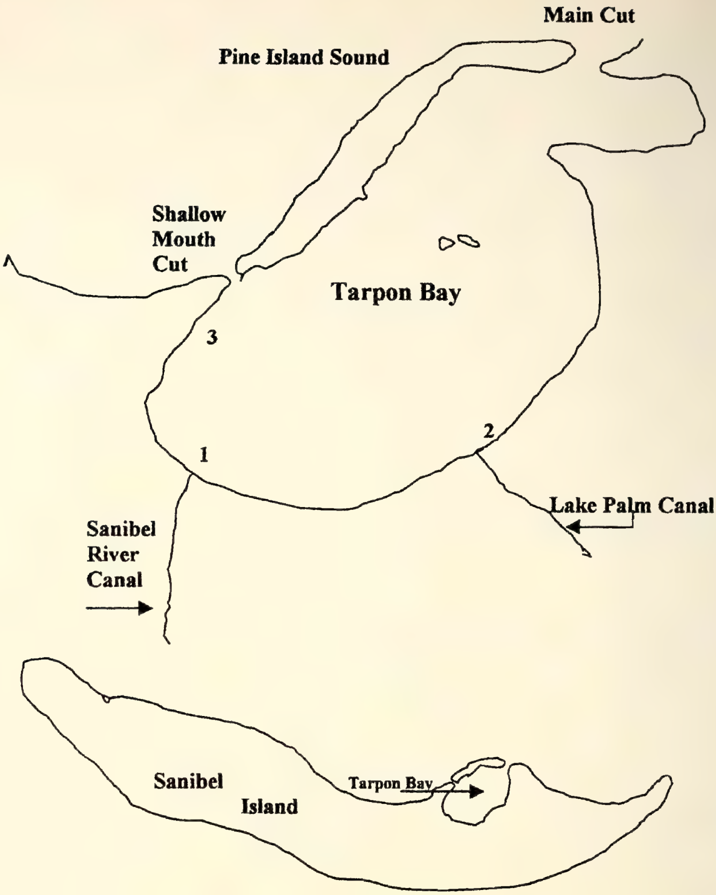

FIG. 1. Map of Tarpon Bay showing approximate locations of the three study sites.

METHODS—We conducted two trials to capture the distinct (bi-modal) seasonality of the south Florida estuarine climate. The first trial (dry season) ran from January 15 to March 11, 1999, when little rainfall occurred and flow through Franklin Lock and Dam (S-79), in cubic feet per second (c.f.s.), was $\bar{x} = 272.7$; ± S.D. = 476.6. During the second (wet season) trial (July 23 to August 31, 1999), flow through Franklin Lock and Dam was $\bar{x} = 2392.6$ c.f.s.; ± S.D. = 2425. We selected 3 sites for pack deployment in Tarpon Bay (Fig. 1). Site 1 was located in the southwest corner of the bay, near the mouth of a creek draining a mangrove swamp; which could potentially experience a higher concentration of fresh water caused by run-off. Site 2 was on the southeast side of the bay, near a small opening draining Lake Palm, a man-made body of water also capable of experiencing a higher concentration of fresh water due to run-off. Site 3 was on the west side of the bay near a small opening into southern Pine Island Sound proper, which could potentially experience lower salinity (in the wet season) or higher salinity (in the dry season). The same three sites were used for both wet and dry season trials. All sites were located in *Thalassia* meadows. Sites remained subtidal with the exception of occasional negative spring tides at Site 2.

Healthy green *Thalassia* blades and *Rhizophora* leaves were picked from plants growing *in situ* and immediately placed in a cooler containing ice and seawater. Fresh plant material was submerged for 48 hours to allow leaching of water-soluble components before initial weights were obtained to standardize the beginning of the experiment (Nykvist, 1959). In the lab, whole *Thalassia* blades were grouped to construct packs of roughly 5g wet weight, and *Rhizophora* leaves grouped to make packs of roughly 7g. In each pack, each leaf/blade was scraped free of obvious epiphytes carefully; so as not to damage its epidermis. The leaves were blotted to remove excess water and then, along with a small plastic identification tag, fastened at the base with a heavy-duty Swiftachment® fastener. A 30 cm monofilament tether was connected to the fastener on each pack. Completed packs were returned to the cooler to await deployment. We constructed 60 packs of each species for each trial; 20 for deployment at each of the three sites. We were careful to avoid desiccation of *Thalassia* blades resulting in acceleration of decomposition if this species is dried before resubmergence (Newell et al., 1986).

We selected the leaf pack technique over the popular mesh bag ("litterbag") method to provide unrestricted access by macroinvertebrate detritivores, as well as other biochemical influences, which might be relevant to the heterotrophic processing rate. Also, we were concerned that small litterbag mesh sizes might become bio-fouled to the point of blocking water flow and causing unnatural conditions of hypoxia.

Loss of fragments does confound attempts to record immobilization/mineralization of elements (Newell et al., 1984). However the leaf pack technique is not expected to isolate such individual mechanisms (and moreover we did not want to exclude any biotic or biochemical influences on the natural plant litter processing). In this regard, mesh bags undoubtedly retain the plant material but may also detract from the natural rate of detrital formation (Wiegert and Evans, 1964).

Field deployment commenced upon completion of all packs; on the same day as collection of plant matter and pack assembly. For the dry season trial we attached leaf packs via monofilament tethers to a PVC pipe. Two pipes were driven 40cm into the sediment at each site; one for anchoring *Thalassia* packs and one for *Rhizophora.* We tethered the packs around the circumference of each pipe at the level of the sediment, allowing the packs to lie naturally in the *Thalassia* bed at each site. It was noted, however, that the *Thalassia* leaf packs were buoyant and strained upward on their tethers immediately upon deployment and thereafter for at least 14 days but not more than 30 days, after which they became increasingly brown in color and for the remainder of the trial were found at sediment level in the grass beds.

In the wet season trial we modified deployment in an effort to decrease time between pack construction and deployment. For each species, a pair of PVC poles anchored a 10m monofilament tether, strung along the sediment surface and fitted with 20 individual loops, securing the leaf packs of that species, spaced roughly every 25cm along the central 4.5m of its length.

For each trial, we retrieved leaf packs 4 times; first after an initial 48h pickup, and subsequently at three times based on the accumulation of thermal energy, counted in degree-days (the cumulative total of water temperature in °C for successive 24-hour intervals). It should be noted that degree day counts were initiated immediately after the 48h pick-ups. Pickups were nominally scheduled for the 300th, 900th and 1200th degree-days after the 48h retrieval. Mission logistics and the actual temperature record produced actual pickups at degree-days 271, 882 and 1,187 during the dry season trial and at degree-days 316, 938 and 1,216 during the wet season trial. At each of these harvest times and at each site, salinity and pH were measured, using a YSI 610-D with 600XL submersible sonde.

Leaf packs were retrieved by carefully placing a 500-micron mesh sieve under each pack to retain fragile portions and macroinvertebrates. *Thalassia* blades were observed from the outset to be particularly fragile and their attachments to the leaf packs exceedingly tenuous. Each pack was placed in a zip-lock™ bag, and moved to a cooler with ice. Upon return to the lab, each pack was gently washed over the mesh sieve, and its invertebrates preserved for later counting. Leaf material from each pack was dried at 50°C for 24 h and weighed to obtain its dry weight. These samples were then ashed in a muffler furnace at 500°C for 4 h and this weight was subtracted from the dry weight to retrieve the weight of organic material. All weights were normalized for *Thalassia* and *Rhizophora* at each site, by calculating the average weight (in grams) of the 5 leaf packs retrieved at the time of the 48-h pickup, to determine compatible percents of weight remaining at each subsequent pickup.

TABLE 1. Log + 1 transformed stepwise regressions of *Rhizophora mangle* dry weight and organic weight percent remaining.

	Dry weight			Organic weight		
Independent variable	Coefficient	F	p	Coefficient	F	p
In						
Degree Day	−0.0004	91.848	0.000	−0.0004	109.715	0.000
Average pH	0.611	70.450	0.000	0.516	47.231	0.000
Out						
Average Salinity	0.119	1.240	0.259	0.127	1.165	0.284
Invertebrate Densities	−0.007	0.004	0.950	−0.140	1.420	0.237

For each leaf pack, the total invertebrate count was normalized to leaf dry weight to produce invertebrate density g/dry weight. Thus, for each leaf pack on each pickup date we were able to determine the percent of dry weight remaining, percent of organic weight remaining, invertebrate density, salinity, pH, degree-days and calendar days since the initial harvesting at 48hr.

We applied a forward stepwise regression to infer the roles of degree-day (thermal energy), salinity, pH and invertebrate density g/dry weight (macro-heterotrophic grazing/shredding) in weight loss; both dry and organic weights. The subject percents of weight remaining were first transformed to Log [X+1] values (the added "1" to address cases of zero weight remaining), where "X" was the percent weight remaining. We used Systat v 7.0 software, to perform stepwise regressions with Alpha-to-enter = 0.05 and Alpha-to-remove = 0.05. Minimum tolerance for entry into the model = 0.1.

RESULTS—*Thalassia* leaf packs were observed to rise off the bottom—when either of the tethering methods was employed—and to remain positively buoyant for as long as 30 days following deployment. At Site 3, on the first pickup during the dry season trial, clear gains in organic weight were exhibited by both species (Tables 4 and 5) and again by *Thalassia* at Site 3, on the first pickup during the wet season trial (Fig. 3, Table 4). In all other cases weight was lost, however by the finish of the dry season trial

TABLE 2. Log + 1 transformed stepwise regression of *Thalassia testudinum* dry weight percent remaining.

	Dry weight		
Independent variable	Coefficient	F	p
In			
Degree Day	−0.001	136.417	0.000
Average pH	−0.295	14.240	0.000
Out			
Average Salinity	0.141	1.696	0.196
Invertebrate Densities	−0.173	2.576	0.122

TABLE 3. Log + 1 transformed stepwise multiple linear regression of *Thalassia testudinum* organic weight percent remaining.

	Organic weight		
Independent variable	Coefficient	F	p
In			
Degree Day	−0.000	88.013	0.000
Out			
Average Salinity	0.036	0.090	0.766
Average pH	−0.224	3.682	0.059
Invertebrate Densities	−0.089	0.553	0.459

none of the *Rhizophora* leaf pack weights had decreased to zero (Fig. 2), nor had many of the *Thalassia* weights by the end of either trial (Fig. 3). The mean percents of the weights remaining and their coefficients of variation are listed for *Thalassia* in Table 4 and for *Rhizophora* in Table 5.

Salinity ranged from a low of 23.8 ppt ($\bar{x}$ = 26.4; ± S.D = 1.77) during the wet season trial to a high of 34.1 ppt ($\bar{x}$ = 33; ± S.D. = 1.01) during the dry season trial. Over the course of the dry season trial, the minimum observed salinity of 30.7 ppt was still higher than the maximum of 27.9 ppt observed during the wet season. Temperature during the dry season trial was as low as 19.5°C ($\bar{x}$ = 22.4; ± S.D. = 1.84) and during the wet season trial

TABLE 4. Mean percent remaining (M.P.R.) and coefficient of variation (C.V.) expressed as a percent for dry weight and organic weight of *Thalassia testudinum.*

	Thalassia testudinum							
	Dry season				Wet season			
	Dry weight		Organic weight		Dry weight		Organic weight	
	M.P.R.	C.V.	M.P.R.	C.V	M.P.R.	C.V.	M.P.R.	C.V.
Pick up 1								
Site 1	87.8	18.6	89.9	16.2	114.6	16.1	98.0	15.3
Site 2	89.1	14.6	89.9	18.4	82.4	16.7	67.6	16.3
Site 3	116.2	10.3	110.2	12.5	134.0	20.8	111.0	20.7
Combined	97.7	14.5	96.7	15.7	110.3	17.9	92.2	17.4
Pick up 2								
Site 1	27.0	30.4	27.9	23.8	73.4	43.6	68.7	42.3
Site 2	42.5	17.1	42.1	14.0	24.0	77.6	17.3	70.7
Site 3	61.7	14.4	64.3	14.4	57.6	21.9	46.7	23.5
Combined	43.7	20.6	44.8	17.4	51.7	47.7	44.2	45.5
Pick up 3								
Site 1	11.5	137.4	NA		57.0	38.1	49.6	36.6
Site 2	14.2	74.0	NA		12.5	140.2	9.8	138.7
Site 3	32.1	34.6	NA		45.8	103.0	36.9	101.2
Combined	19.3	82.0	NA		38.4	93.8	32.1	92.2

TABLE 5. Mean percent remaining (M.P.R.) and coefficient of variation (C.V.) expressed as a percent for dry weight and organic weight of *Rhizophora mangle.*

	Rhizophora mangle							
	Dry season				Wet season			
	Dry weight		Organic weight		Dry weight		Organic weight	
	M.P.R.	C.V	M.P.R.	C.V.	M.P.R.	C.V.	M.P.R.	C.V.
Pick up 1								
Site 1	89.2	16.5	84.0	17.1	64.2	22.3	59.7	22.2
Site 2	83.9	10.7	80.9	9.7	94.2	8.4	90.0	7.8
Site 3	107.2	13.7	104.4	13.3	80.7	24.7	78.8	23.9
Combined	93.4	13.6	89.8	13.4	79.7	18.5	76.2	18.0
Pick up 2								
Site 1	71.1	23.3	67.3	23.9	31.7	87.2	27.1	86.0
Site 2	74.3	10.6	71.0	10.6	77.7	37.7	62.0	36.5
Site 3	89.0	15.6	83.1	17.7	21.3	69.0	18.5	77.0
Combined	78.1	16.5	78.3	17.4	43.6	64.6	35.9	66.5
Pick up 3								
Site 1	43.8	40.1	NA		0.0	0.0	0.0	0.0
Site 2	68.9	19.0	NA		24.0	96.4	20.2	96.2
Site 3	32.1	34.6	NA		0.0	0.0	0.0	0.0
Combined	48.3	31.2	NA		8.0	32.2	6.7	32.1

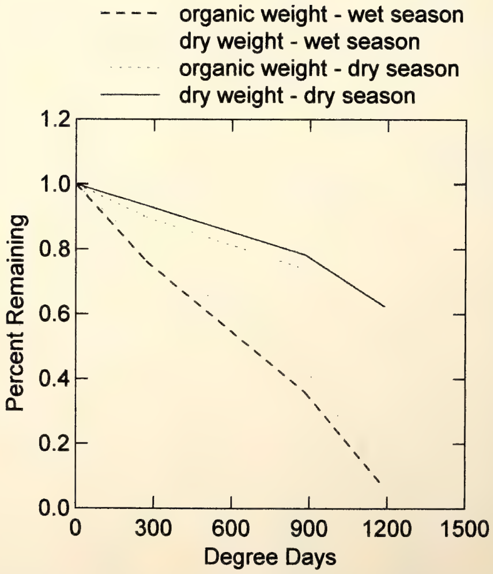

FIG. 2. Mean percent remaining of *Rhizophora mangle* (sites combined) dry weight and organic weight for wet and dry seasons.

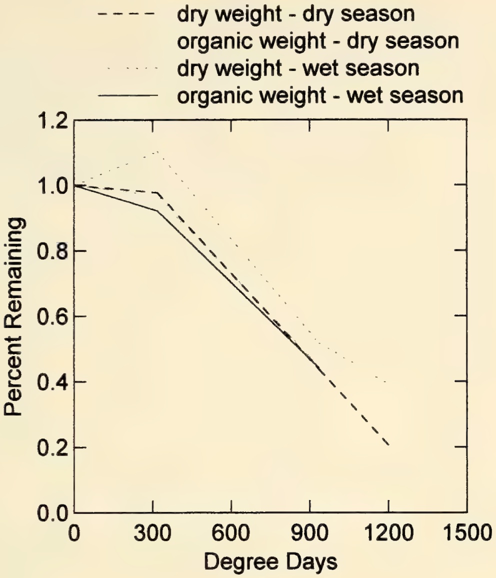

FIG. 3. Mean percent remaining of *Thalassia testudinum* (sites combined) dry weight and organic weight for wet and dry seasons.

as high as 35.7°C (x̄ = 31.5; ± S.D. = 1.91), with no overlap between the dry season high of 23.6°C and the wet season low of 23.8°C. The observed pH ranged between a low of 7.8 (x̄ = 8.0; ± S.D. = 0.15) during the wet season trial and a high of 8.8 (x̄ = 8.4; ± S.D. = 0.07) during the dry season trial, with slight overlap between the dry season low of 8.3 and the wet season high of 8.5. Invertebrate densities observed on *Rhizophora* ranged between a low of 0.0/g dry wt. (x̄ = 4.1; ± S.D. = 1.45) during the dry season trial and a high of 9.3/g (x̄ = 3.3; ± S.D. = 2.45) during the wet season trial, with substantial overlap between the wet season low of 1.3/g and the dry season high of 6.7/g. Similarly, on *Thalassia,* invertebrate densities ranged between a low of 0.0/g (x̄ = 8.6; ± S.D. = 4.2) during the dry season trial, to a high of 58.4/g (x̄ = 18.9; ± S.D. = 10.2) during the wet season trial, with extensive overlap between the wet season low of 2.7/g and the dry season high of 20.7/g. The taxonomic composition of invertebrates captured in leaf packs is described in Table 6.

These above invertebrate counts included sporadic captures of large, more transient invertebrates, including mud crabs (*Rhithropanopeus harrisii*), banded tulips (*Fasciolaria lilium), Cerithium* sp. (gastropod) and a brittle star (Ophiuroidea). Unrelated to these specific captures, we also found evidence suggesting additional predation in the form of large, ragged sections lost from *Rhizophora* leaves, which appeared to have been masticated by unknown organisms.

Stepwise regression of log + 1 transformed data eliminated all independent variables insignificant to weight loss of leaf material. Both *Rhizo-*

TABLE 6. Numerical abundance (N.A.) and percent species composition (% S.C.) of invertebrate taxa captured in leaf packs.

	Thalassia testudinum				*Rhizophora mangle*			
	Dry season		Wet season		Dry season		Wet season	
Taxa	N.A.	% S.C.	N.A.	% S.C.	N.A.	% S.C.	N.A.	% S.C.
Bulla striata			5	1.0			8	6.0
Cerithium sp.			3	0.6				
Cymadusa compta	204	99.5	367	70.3	222	98.7	48	36.1
Farfantepenaeus duorarum			1	0.2			1	0.8
Fasciolaria lilium			1	0.2				
Gastropoda (unidentified)			87	16.7			35	26.3
Harrieta faxoni			7	1.3	2	0.9		
Nassa sp.			4	0.8			5	3.8
Ophiuroidea							1	0.8
Polychaete			33	6.3			14	10.5
Paguridae	1	0.5	8	1.5			1	0.8
Rhithropanopeus harrisii			2	0.4	1	0.4	10	7.5
Turbinella sp.			4	0.4			10	7.5

phora dry weights and organic weights were significantly related to degree days and pH (Table 1) exhibiting r^2 values of 0.643 and 0.733, respectively. Degree days and average pH were significant to leaf material loss for *Thalassia* dry weights (Table 2), whose coefficient of determination (r^2) was 0.646. In the case of *Thalassia* organic weights, only degree days were significant (Table 3) ($r^2 = 0.553$).

DISCUSSION—*Rhizophora* and *Thalassia* weight losses using the leaf pack technique in this estuarine environment were not attributable to all measured variables indicative of the processes expected to be significant in coarse detrital litter turnover. The lack of significance ($p > 0.05$) among the monitored variables, with the exception of degree days and pH indicated that some other factor(s) played important roles in the weight loss / processing of leaf packs and/or that the sampling for these parameters was inadequate. Sampling for water-quality indices only at the times of harvesting could easily have failed to characterize the chronic levels of these parameters occurring and presumably affecting decomposition during the intervening periods.

A major factor influencing the processing of macrophyte decomposition has been identified as the physical breakup of the particulate matter, which may occur due to water movement (Rublee and Roman, 1982). In our experiments, *Thalassia* blades remained positively buoyant for up to 30 days, consistent with reports by Newell and co-workers (1986). This phenomenon may have produced unnatural strain at the points of leaf attachment in both of the tethering methods we employed. This was in contrast to the surface flotation which would otherwise have occurred naturally, and it seemed like-

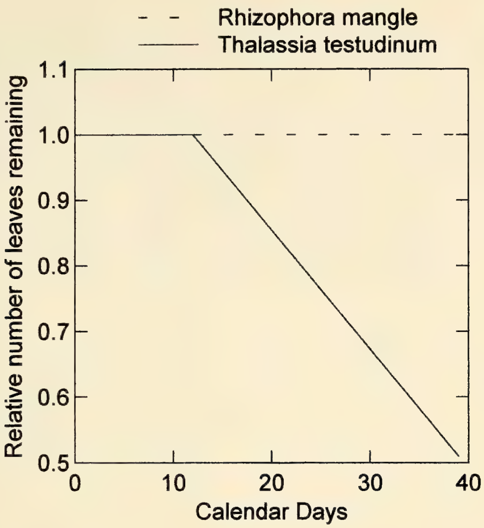

FIG. 4. Relative number of leaves remaining in packs for *Rhizophora mangle* and *Thalassia testudinum* during the course of the dry season trial.

ly that the unnatural suspension and restraint within surface currents could easily have been responsible for a substantial loss of material from *Thalassia* leaf packs.

Serendipitously, we had collected limited data suitable to examine this hypothesis. During the dry season trial, the number of individual leaves in each pack harvested was counted prior to drying and ashing. Although transport from the pickup site to the lab had fragmented a number of packs, some 36 *Thalassia* and 33 *Rhizophora* packs remained undisturbed sufficient to permit accurate leaf counts. We normalized these to the mean number of leaves per the packs retrieved at 48h; 12.3 blades per *Thalassia* pack and 4.9 leaves per *Rhizophora* pack, to calculate the relative numbers of leaves remaining in each of the packs subsequently harvested. These data (Figure 4) show that, at sometime after 12 days, the loss of *Thalassia* blades became substantial—about 50%, on average—while losses from *Rhizophora* packs remained stable (negligible) through to the 39 day pickup. Likewise, the coefficients of variation for *Thalassia* packs continued to increase, indicating that losses were not systematic and remained irregular between packs, whereas those of *Rhizophora,* starting from the same low values (about 0.1), stayed low throughout the trial.

It was this substantial and nonsystematic loss of whole *Thalassia* blades—and, presumably, blade fragments as well—which is thought to be a major influence on its weight losses in our experiments. While the leaf pack technique is intended to mimic a natural detrital formation, tethering the *Thalassia* leaf packs in suspension above the bottom produces unnatural physical stresses which, in our experiments, clearly gave rise to substantial and irregular weight loss. This confounding effect would likely lead to erroneous estimates of ecosystem health and therefore invalidates the use of *Thalassia* for the methods employed in this study. Inappropriate *Thalassia* weight loss due to fragmentation has been observed in previous studies (Newell, 1984). In contrast to *Thalassia,* tethered *Rhizophora* packs were noted to sink to the bottom within two days of deployment, and remain there, mimicking a natural detrital formation and therefore avoiding the confounding effects on weight loss experienced by the *Thalassia* leaf packs.

Field observations of fuzzy, white, fungi-like coatings developing on the leaves of *Rhizophora* clearly suggest that a microbial colonization and growth process was a significant component of the *Rhizophora* processing we documented in Tarpon Bay. Clear evidence of early weight gains (particularly at Site 3) indicates that such growth began very quickly if not immediately on deployment, as has been reported for other south Florida estuaries (Fell and Master, 1973). For example, marine *oomycetes* have been found to begin colonization of *Rhizophora mangle* leaves within 2h of submergence, and to reach 100% frequency of occurrence within 30h (Newell et al., 1987). Bacteria have also been observed to increase rapidly during the initial periods of experiments involving *Rhizophora stylosa* (Robertson, 1988). In our experiment, the presence of a weight-gain component within an overall weight-loss phenomenon suggests the simultaneous influences of both production and decomposition processes, as has been concluded by Newell and co-workers (1984).

Stepwise multiple regression did not validate invertebrate densities as a significant factor contributing to the processing / weight loss of either *Thalassia* or *Rhizophora* in this experiment. However other observations suggest that this result may have arisen primarily from an insufficiency in the frequency of sampling; that weight losses attributable to macro-invertebrates were not insignificant. The numerically dominant invertebrates captured in our samples were amphipods (*Cymadusa compta*), which did not appear particularly transient; they were almost always found nestled between leafs/blades comprising the pack. However, sporadic capture of larger, more mobile invertebrates, including mud crabs (*Rhithropanopeus harrisii*), banded tulips (*Fasciolaria lilium*), *Cerithium sp.* (gastropod), and brittle star (Ophiuroidea), and—perhaps more importantly—evidence of additional predation in the form of what appeared to be large masticated areas on *Rhizophora* leaves, unrelated to the above captures of large individuals, were also observed. It appeared that larger invertebrates could have—and did—consume material from the leaf packs during the periods in between sampling, which was thus unaccounted for by the invertebrate sampling. Because of the sizes of both the masticated areas and the observed individuals, and because of their mobility relative to the very low frequency of sampling, we feel that our invertebrate count may have greatly underestimated the true predation by macroinvertebrate consumers on the leaf packs in Tarpon Bay.

Although further investigation of such macroinvertebrate predation is warranted, deployment of *Rhizophora* in the present leaf-pack methodology does appear to have worked well in Tarpon Bay, responding to relevant biotic and environmental influences. In contrast, use of *Thalassia,* in the present leaf-pack design, cannot be relied upon as a means of characterizing the ecosystem health or trophic functioning of Tarpon Bay due to excessive blade loss from *Thalassia* leaf packs. To achieve general utility, a modification to successfully employ *Thalassia* would, at a minimum, require radical redesign of both the pack attachment and deployment characteristics, preferably to better mimic the natural flotation and subsequent formation of *Thalassia* detritus. Such modifications would require validation in south Florida estuarine environments; these are logical goals for future work.

Nevertheless, in Tarpon Bay both species—even the *Thalassia* as deployed in the present leaf-pack method—responded, in some instances, to what appeared to be immediate (or very rapid-onset) colonization by microbiota; an important component of estuarine ecosystem function in its own right (Odum, 1970). Although prior findings are scarce, some (Hyde, 1992a, b and c) suggest that variation in salinity might have a substantial impact on at least some of these colonizing microbiota. In addition, other researchers (Newell et al., 1984; Hyde and Lee, 1995) have called for further investigation of the role played by fungi in the decomposition of leaf litter. An assay targeting such microbial colonization, if indeed sensitive to salinity variations, could yield a powerful bio-indicator of the impacts of freshwater releases in the Caloosahatchee River Estuary.

Given its fragility, *Thalassia,* in particular, might prove to be suited only to such a shorter-duration assay, requiring perhaps 12 days or less to reach completion, while conferring the general advantage of being much more rapid than the 30–50-day method employed here. Therefore the potential utility of a short-duration leaf-pack assay for the onset of microheterotrophic processing of these two species—*Thalassia* and *Rhizophora*—should be investigated as a primary goal of future research.

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Florida Committee on Rare & Endangered Plants & Animals: Dr. Dean Bagley, University of Central Florida, and Ms. Laura Finn, Fly By Night, Inc., Co-Chairs.
Geology/Hydrology: Dr. Rick Copeland, Florida Dept. of Environmental Protection..
Medical Sciences: Dr. Roseann White, University of Central Florida.
Physics and Space Sciences: Dr. Hamid Rassoul, Florida Institute of Technology.
Science Teaching: Dr. Randy Criss, Saint Leo University.
Social Science: Dr. Hudson Reynolds, Saint Leo University.
Urban & Regional Planning: vacant.

2001 PROGRAM ISSUE

THE SIXTY-FIFTH ANNUAL MEETING OF THE FLORIDA ACADEMY OF SCIENCES

in conjunction with the
Florida Junior Academy of Science
and the Science Talent Search

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Featuring Two Special Sessions
Understanding Karst is Key to Protecting Florida's Springs - A Symposium
Biogeochemical Studies in Florida Bay, the Everglades, and their Watersheds

Two Plenary Addresses:
The Medalist Address
The Dumbing Down of Medicine
by Richard F. Lockey, M.D.
&
The Gale Plenary Lecture
Speaker to be Announced

Saint Leo University
Saint Leo
March 8-10, 2001

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PRESIDENT'S WELCOME

I am delighted to have this opportunity to welcome all participants to the Sixty-fifth Annual Meeting of the Florida Academy of Sciences. As we gather together here at Saint Leo University, we humbly note the venerable history of the Academy and enthusiastically look to the challenges and opportunities of its future. We are deeply grateful to include among our number all those who have promoted scientific research, stimulated interest in the sciences, encouraged the diffusion of scientific knowledge, sponsored good scientific teaching and promoted the ethical application of the sciences to the service of humanity. And, as we look to the future, we also note that these are exciting times for the Academy. We are solidly grounded on a course of growth and development. We all must commit to actively contribute our share not only during the next few days we spend here together but also into the future. Please join me in seizing the opportunity to build on past achievements and continue to work to sustain an Academy to which we can all point with pride.

Maribeth Durst

MEETING INFORMATION

The 65th Annual Meeting of the Florida Academy of Sciences will be held at Saint Leo University in Saint Leo, Florida from March 8-10, 2001. At. 1:00 PM Friday, March 9, the Gale Plenary Lecture will take place, immediately following the Annual Business Meeting. Following the Academy Banquet on Friday night, Richard F. Lockey, M.D., the 2000 Academy Medalist, will give the Annual Medalist Address. Two special sessions are also planned. The subject for one is Biogeochemical Studies in Florida Bay, the Everglades, and their Watersheds. The other will be a Springs Symposium, featuring numerous papers, inportant films relating to springs, and a field trip to two well-known springs and a State Archeological site.

LOCATION

Saint Leo University is an independent Catholic, coeducational, liberal arts-based institution offering programs leading to the baccalaureate degree, and the Master of Business Administration, Master of Education, and Master of Psychology degrees. The university's main campus is located approximately twenty-five miles northeast of Tampa. The University also offers degree programs at seventeen extension centers in Florida, Virginia, Georgia, South Carolina and Texas. With over 1,000 students on its main campus and 7,000 enrollments at its extension centers, Saint Leo ranks among the twenty largest Catholic institutions in the United States.

As the first Catholic college in Florida, Saint Leo was established by Benedictine monks and chartered on June 4, 1889. In 1920, the college was phased out as the monks decided to focus their efforts on developing a college preparatory school. Since Saint Leo's charter as an institution of higher education had never expired, the monks were able to reconsider the institution's direction in 1959, and began offering the associate degree. In 1964 they closed the prep school, and in 1967 they began offering the bachelor's degree. In 1969 the college was reorganized when the Order of Saint Benedict of Florida transferred title and control to an independent Board of Trustees. In 1973, the college responded to requests from the armed services to offer degree programs on military bases. Due to the successful growth of these academic programs, Saint Leo eventually became the sixth largest provider of higher education to military-related personnel in the United States.

Saint Leo University is located on State Road 52 approximately four miles east of I-75, exit #59, and about twenty-five miles northeast of Tampa. Further details about Saint Leo and vicinity, including location and campus maps, will be provided in the Program Issue of the *Florida Scientist* (Supplement 1 to Volume 64). This and other relevant information will also be posted on the FAS website (http://www.cas.usf.edu/FAS) or contact the Program Chair at lovejoyd@pbac.edu).

REGISTRATION

ALL PARTICIPANTS ARE EXPECTED TO REGISTER. Academy members receive the Program Issue by mail in advance, as will non-members who register before February 1, 2001. Additional meeting material (including programs for individuals registering after February 1, 2001) will be available at the registration desk, which will be open on Thursday afternoon, March 8, from 3:00-5:30 PM and Friday, March 9, from 7:30 AM until 4:00 PM. For a downloadable registration form, email lovejoyd@pbac.edu

LODGING

No reservations can be made through the Academy. The following hotels have agreed to reserve rooms at the special conference rates shown if you identify yourself with the Florida Academy of Sciences meeting at Saint Leo University. Early reservations are encouraged

- Saddlebrook Golf and Tennis Resort (fifteen minutes from Saint Leo)
  Wesley Chapel, FL 33544, Exit 58, I-75, on SR 54 (800) 729-8383
  $195 (single) to $370 (four persons). Shuttle service available to Tampa airport

- Masters Economy Inn (ten minutes from Saint Leo)
  27807 State Road 54, Wesley Chapel, FL 33544 (Exit 58, I-75)
  (813) 973-0155
  $45.00 (1-4 persons)

- Comfort Inn (ten minutes from Saint Leo)
  5642 Oakley Blvd., Wesley Chapel, FL 33544 (Exit 58, I-75)
  (813) 991-4600
  $45.00 (single or double), $5.00 per additional person

- Holiday Inn Express (ten minutes from Saint Leo)
  27615 State Road 54, West Wesley Chapel, FL 33544 (Exit 58, I-75)
  (813) 907-1379
  $55.00 (single or double), $5.00 per additional person

- Wingate Inn - Tampa North (20 minutes from Saint Leo)
  17301 Dona Michelle Dr., Tampa, FL 33647 (Exit 56, I-75)
  (813) 971-7676
  $79.00 (deluxe double or king room); $99.00 mini-suite

The Local Arrangements Committee has information on other lodgings within easy driving distance from Saint Leo. This information is available by phone at 352-588-8339.

MEALS

The Academy Banquet will be held on Friday evening (March 9) in the William P. McDonald Center at Saint Leo University beginning at 6 PM with a cash bar. The dinner will be a choice of Prime Rib, Grilled Salmon, or Vegetable Plate. Pre-registration for the banquet is suggested as only a limited number of tickets will be available on the day of registration.

Complementary lunches will be provided at 12:00 PM on Friday (March 9) for those who pre-register before February 1, 2001. Information about local restaurants within a few minutes drive of Saint Leo will be available by phone at 352-588-83339 or at the registration desk

ACADEMY PLENARY SESSION & BUSINESS MEETING

The Gale Plenary Lecture will be given on Friday, March 9, at 1:00 PM in the Selby Auditorium, immediately following the Annual Business Meeting. The speaker for the Gale Plenary Lecture has not yet been announced.

MEDALIST PRESENTATION

Richard F. Lockey, M.D., the 2000 Academy Medalist, will present the Annual Medalist Address immediately following the Banquet Friday evening. Dr. Lockey is Joy McCann Culverhouse Professor in Allergy and Immunology at the University of South Florida's College of Medicine, and Director of the Division of Allergy and Clinical Immunology at the James A. Haley Veterans' Hospital in Tampa. The title of his address is "The Dumbing Down of Medicine."

FIELD TRIPS

A Springs Field Trip to Homosassa and Rainbow Springs (Citrus and Marion Counties), as well as the Crystal River State Archeological Site, will be held on Saturday, March 10. Participants will see first hand the unique characteristics of Florida springs, and guides will discuss how humans threaten these springs and how we can protect them. This trip is sponsored by the Southeastern Geological Society in association with the Hydrogeology Consortium. For further information regarding the field trip, contact Kyle Champion (SWFWMD) at (813) 985-7481.

LOCAL ARRANGEMENTS

The Local Arrangements Chair for this Meeting of the Academy is Dr. George M. Dooris of Saint Leo University (352-588-8339, email george.dooris@saintleo.edu). He may be consulted for any special meeting needs.

SPECIAL SESSIONS

1. Understanding Karst is Key to Protecting Florida's Springs – A Symposium

This special session is being planned by Dr. Rick Copeland, Chair of the Geology/Hydrology Section. A selection of important films relating to springs will be shown on Friday afternoon, and on Saturday a field trip to several springs and a State archeological site will be conducted.

2. Biogeochemical Studies in Florida Bay, the Everglades and their Watersheds

This Joint Session of the Atmospheric and Oceanographic Sciences Section and the Environmental Chemistry and Chemical Sciences Section is being organized by Dr. John H. Trefry and Dr. William J. Louda. The Joint Session begins at 10:30 AM on Friday morning.

FLORIDA JUNIOR ACADEMY OF SCIENCE ANNUAL COMPETITION

The Junior Academy will meet with Florida Academy of Sciences this year. As the student division of FAS, the Florida Junior Academy of Science provides opportunities that encourage middle and high school students in science by allowing them to compete, share, and network with other students and adults having common interests. The focus of this "common bond" among participants is their research activities. The Florida Junior Academy of Sciences is seeking volunteers to assist in judging and to act as section moderators at its meeting, to be held on Saturday afternoon (March 10). The Junior Academy is also seeking individuals in early February to evaluate research papers submitted for this meeting. Persons interested in participating in this rewarding experience should contact the FJAS Coordinator: Pat Zalo, 2812 26th Avenue Drive W., Bradenton, FL 34205-3707, telephone 941-756-4156, email pzalo@yahoo.com

COMMERCIAL AND INSTITUTIONAL EXHIBITS

Space is available on a first come-first served basis for a fee of $75.00. Exhibits by research institutions or programs and others of an informational nature may be given free space. Parties interested in fee or free spaces should contact the Local Arrangements Chair for details.

STUDENT AWARDS

Students presenting papers at the Annual Meeting of the Academy and who are registered for the Meeting may be considered for a number of awards. Details are presented below. Students wishing to be considered for one or more of these awards should indicate their interest on the Abstract Submittal Form.

1. Outstanding Student Papers Award - This award is presented by any of the Academy Sections to graduate and/or undergraduate students.

2. American Association for the Advancement of Science Award - This award is presented to one male and one female undergraduate student annually and is a one-year membership in AAAS including the journal, *Science*.

3. Central Florida Chapter, The Explorer's Club Award – a prize of $500.00 may be awarded for the "most original student research paper in the spirit of exploration." The prize for the winning paper is awarded when the student presents the paper again at an Explorer's Club banquet in Orlando.

4. Sigma Xi Awards - The first award, presented by the University of Florida chapter of Sigma Xi, is for $50 and a certificate. This award is presented to graduate students only. The second award is presented by Florida Institute of Technology for the best paper by a Florida Tech student. The award is for $50 and $100 for undergraduate and graduate students respectively.

5. William W. Behrens, Jr./Florida Institute of Oceanography Award - This $750 prize is awarded by the Florida Institute of Oceanography to a graduate student for the best paper in any area of ocean or marine sciences. A written manuscript is required and must be submitted by February 13, 2001 to: Dr. Ernest D. Estevez, Chairman, FAS Awards Committee, Mote Marine Laboratory, 1600 Ken Thompson Parkway, Sarasota, FL 34236, telephone 941-388-4441. Please, no facsimile or email submittals.

ANNOUNCEMENTS

YEAR 2002 MEETING: The Annual Meeting for Year 2002 will be held at Barry University, March 7-9, 2002

PERMANENT OFFICES FOR THE ACADEMY: The FAS office is located at the Orlando Science Center. The Executive Director is Dr. Gay Biery-Hamilton. The address and telephone numbers are shown below.

Florida Academy of Sciences
Orlando Science Center
777 East Princeton St.
Orlando, FL 32803
407-514-2079

FLORIDA ACADEMY OF SCIENCES
2001 ANNUAL MEETING PROGRAM SUMMARY

THURSDAY, MARCH 8

TIME	EVENT
3:00 PM – 5:30 PM	Registration, Lewis Hall
5:30 PM – 7:00 PM	Dinner on your own at local restaurants (information at Registration Desk)
7:00 PM	FAS Council Meeting - Raleigh Greene Room McDonald Student Center

continued, next page

FAS MEETING SUMMARY, continued

FRIDAY, MARCH 9

TIME	EVENT
7:30 AM – 4:00 PM	FAS Registration & Information Desk Lewis Hall
8:00 AM – 12:30 PM	FAS Concurrent Paper Sessions Lewis Hall
12:00 PM – 2:15 PM	Lunch, Cafeteria, McDonald Student Center Business Meeting & Gale Plenary Lecture Selby Auditorium
2:30 PM – 5:00 PM	FAS Concurrent Paper Sessions Lewis Hall
6:00 PM – 7:00 PM	Reception Cafeteria, McDonald Student Center
7:00 PM – 10:00 PM	FAS Banquet & Medalist Address Cafeteria, McDonald Student Center

SATURDAY, MARCH 10

TIME	EVENT
8:30 AM – 12:00 PM	FAS Registration & Information Desk Lewis Hall
8:30 AM – 12:00 PM	FAS Concurrent Paper Sessions Lewis Hall
8:30 AM – 4:30 PM	Springs Field Trip
10:30 AM – 11:30 AM	Junior Academy Symposium Marmion Cafeteria
12:00 PM	Lunch on your own at local restaurants (information at Registration Desk)
AFTERNOON	Trips to various local attractions (information at Registration Desk)

AGRICULTURAL AND NATURAL RESOURCES

FRIDAY 9:30 AM LEWIS 119
SESSION A
MARK A. WADE, INDIAN RIVER RESEARCH AND EDUCATION CENTER, UNIVERSITY OF FLORIDA, presiding

9:30 AM AGR-1 Profitability Issues in Florida's Citrus Industry. T. GERAKARIS, K. GILMORE, B. MCBEE, J. ODOM, AND M. WADE, University of Florida, 2199 South Rock Road, Fort Pierce, FL 34945. Growers face many problems in the Florida citrus industry. Uncertainty of weather, pests, disease and price volatility are risks that must be managed, all in the face of declining industry profits. As economic pressures force industry wide and global change, citrus producers and consumers are impacted. Growers must respond to higher input prices, lower output prices, foreign competition and technological change. Consumer demographic changes influence the demand for citrus, while supply factors influence retail citrus prices. Concepts of market strategy, globalization, export targets, product branding and market structure are examined from a profitability standpoint. Decision Information Systems for Citrus (DISC) are profiled as tools which can be utilized by growers to predict possible profits or loss at grove maturity. This research concludes that in order to maximize profits, or minimize losses, growers must actively participate in the technological and marketing evolution that is occurring in the citrus industry.

9:45 AM AGR-2 *Episimus utilis* for Biological Control of Brazilian Peppertree. CLIFF G. MARTIN AND JAMES P. CUDA; Dept. of Entomology and Nematology; University of Florida, PO Box 110620, Gainesville, FL 32611-0620. I investigated *E. utilis* for possible control of Brazilian peppertree (BP)--a troublesome weed in central and south Florida -- and found the following results: 1. When provided Gatorade R, adults lived longer and yielded more eggs than those given ten percent honeywater, deionized water, or an empty vial. Because of high experimental error, however, the treatment differences were insignificant. Food supplements affected adult survival and egg production less than other unknown factors. 2. Biological parameters such as size and duration of each life stage were also determined. 3. Three life tables, survival curves, lambdas, doubling times, and growth curves were also determined for each cohort. 4. I also found how to successfully rear the moths. This information will hopefully aid in mass rearing and performing host-range tests of *E. utilis*.

10:00 AM AGR-3 Strategic Planning for the Establish of an Eco-Tourism Operation. T. M. MINTON AND M. A. WADE, Food and Resource Economics Dept., University of Florida, Indian River REC, 2199 South Rock Road, Fort Pierce, FL 34945. Whether you are a private landowner or a public lands manager, eco-tourism may provide alternative income streams and access to a diversified customer base. Eco-tourism, or nature-based tourism, blends the wonders and beauty of nature with the desire to get away from the routine of everyday life. This does not imply that eco-tours are tranquil and sedate. White water rafting, biking, hiking, and scuba diving all qualify as eco-tourism. This research was designed to provide decision-makers with a structured approach to creation of a strategic plan. While motivation and profit seeking functions may differ between public and private parties, both must develop a clear vision or mission, accurately evaluate available resources, develop a long range plan, and successfully market the venture. This study progressed from creation of the enterprise vision, resource evaluation (personnel, financial, facilities, environmental), needs and interest surveys, partnership formation, long range goals and planning, and development of a successful niche or main-stream market strategy.

10:15 AM AGR-4 An Analysis of Florida and Sao Paulo's Citrus Costs and Returns: 1980-2000. C. C. RAMOS (1), M. A. WADE (2), AND E. M. NEVES (1), (1) University of Sao Paulo, Av. Padua Dias, 11CX. Postal 9-CEP, 13418-900 – Piracicaba - SP, Brazil, (2) University of Florida, 2199 South Rock Road, Fort Pierce, FL 34945. Within the U.S., Florida accounted for over 84% of the country's orange production while the State of Sao Paulo produced over 82% of Brazilian fruit in 1999. Growers in Sao Paulo have few irrigated groves, and use less input, such as chemicals and fertilizers, relative to Florida growers. Florida citrus producers have much higher labor expenses, especially harvest labor, relative to Brazilian growers. These differences afford Sao Paulo growers a lower cost of production and a lower level of productivity. In addition, different production systems, and social and economic environments result in cost and return differences between the two regions. The objective of this research was to evaluate cost and return differences for processed oranges in Florida and Sao Paulo during the 1980's and 1990's, and to analyze changes in profitability in the citrus industry during this same period. Results indicate that Florida growers had higher costs of production, higher productivity and higher profits during this time period, relative to Sao Paulo growers. However, over the two decades studied, Brazilian input efficiency increased as their use of chemicals and fertilizers increased, narrowing the cost of production gap between the two regions. The main determinant of profitability in Florida has been productivity and prices received, while in Sao Paulo, cost of production has been the primary determinant of profitability.

10:30 AM BREAK

10:45 AM AGR-5 Seasonal Distribution of Pest Mole Crickets in South-central Florida. M.B. ADJEI (1) AND C.S. GARDNER (2). (1) University of Florida, Range Cattle Research and Education Center, Ona, Florida 33865-9706, (2) Florida A&M University, Div. Of Agric. Sciences, Tallahassee, Florida 32307. Foreign mole crickets cause approximately $100 million worth of damage to pastures and the turf industry in Florida, yearly. A primary objective of this study was to use pit-fall traps to develop population histories of juvenile tawny and southern mole crickets on pastures in south-central Florida. A secondary objective was to monitor adult mole cricket population during mating flight period with sound emitting traps. Six pit-fall traps were installed on a 4-ha pasture at one site each in Desoto, Manatee and Pasco counties, at two sites in Hardee county, and three sites in Polk county. Numbers of mole crickets/trap and rainfall amount were recorded separately for each site weekly from July 1997 through December 1999. The distribution of juvenile pest mole crickets on pastures followed an exponential pattern over time. Nymphs first appeared in June and increased to a peak (35-50 mole crickets/trap/week) between July and August, with the exact time for the peak incidence being modified by the period of early summer major rainfall (>2.5 cm) episode. Subsequently, numbers of mole crickets declined exponentially through the fall except when hurricane floods forced adults to relocate. Pest mole crickets exhibited very little soil surface activity between December and January as adults overwintered deeper in the soil. Tawny adult mating flights were confined to mid-February and April in south-central Florida, whereas adult southern mole cricket flights extended from April to August. These results indicate that the most appropriate period for monitoring juvenile pest mole crickets on pasture in south-central Florida is from June to September but adult mole crickets should be monitored with sound traps after mid- February. Additionally, pest population surveys developed from this study are being used to test the efficacy of the mole cricket nematode (*Steinernema scapterisci)* in south central Florida.

11:00 AM AGR-6 An Economic Analysis of Caribbean Fruit Fly Control in Citrus. M. EGAN, J. BEACHHAM, M. BASS, AND M. WADE, University of Florida, 2199 South Rock Road, Fort Pierce, FL 34945. Since its introduction to the state, the Caribbean Fruit Fly, *Anastepha Suspensa*, has damaged Florida's citrus industry. The female fruit fly oviposts in the host fruit; the egg hatch into larvae, which then feed on the fruit pulp. This contamination damages the fruit itself and results in the need for quarantine treatments for citrus shipments to certain states and countries, including China, Japan, Australia and California. Access to these lucrative markets requires that fruit be certified as "fly free". This research examines the economic costs and returns associated with Caribbean Fruit Fly control. Two hypothetical grove situations are modeled using negative trapping and bait sprays. Fruit exports to Japan and Europe are available to Grove A, which controls fruit flies. Grove B is limited to domestic marketing due to fruit fly contamination. Cost of fruit fly control, pack out rate, markets and prices received are explored. Results reported in the study found that while controlling fruit flies is not an overall monetary threat to citrus producers, the increase in revenues, which can be generated through foreign markets, more than offsets the increase in costs incurred by fly control.

11:15 AM AGR-7 Harborside Works: A Marine Science Research Center Partnership for Enhancing High School IB Biology Curriculum. HOLLIS HOIER, Science Department, Lincoln Park Academy, 1806 Avenue I, Fort Pierce, FL 34950. Lincoln Park Academy's International Baccalaureate (IB) biology students experience their required IB laboratory components via curriculum coordinated, team taught marine science explorations at Harbor Branch Oceanographic Institution (HBOI), Fort Pierce, Florida. The education coordinator at HBOI's Education Center and LPA's lead teacher create matching field and/or laboratory lectures, data collection and analysis activities to promote student understanding of the more challenging topic areas. Students are exposed to and gain experience with numerous state of the art biotechnologies while being exposed to science professionals of all kinds. The depth of understanding and career awareness acquired by these students are the premiere aspects of this LPA-Harborside Program.

11:30 AM AGR-8 Pasture Improvement Practices Utilized by Florida Cattlemen. M. A. WADE, T. M. MINTON, AND L. DELARGY, Food and Resource Economics Dept., University of Florida, Indian River REC, 2199 South Rock Road, Fort Pierce, FL 34945. Pasture improvement has long been established as a way to increase the carrying capacity of Florida ranches. Herd sizes can be increased through intensive grazing and aggressive pasture management, or current herds can be maintained on less acreage when denser, more nutrient rich forages are available. Environmentally, this practice is preferred because marginal, environmentally less stable lands can be taken out of production. Current practices for pasture improvement in the state of Florida are varied. Depending on the source, improved pasture can be defined as native grassland which has been fertilized, native pasture which has been overseeded, rangeland which has been disked and planted at some time in the past, but has been ignored since, or any number of combinations. The objectives of this research were to (1) derive a standard definition of "improved" pasture, (2) generate elasticity of demand estimates, (3) evaluate current attitudes and intentions of cattlemen on pasture improvement, (4) determine the number of acres of improved pasture, and (5) to evaluate the cost of pasture improvement in Florida. Data was generated via a comprehensive written probability survey of both commercial cattle and smaller operations. List frames from the Florida Cattlemen's Association were used. Results are discussed by region and size of operation.

FRIDAY 2:30 PM LEWIS 119
SESSION B
MARK A. WADE, INDIAN RIVER RESEARCH AND EDUACATION CENTER, UNIVERSITY OF FLORIDA, presiding

2:30 PM AGR-9 A Survey of Hormonal Activity in Florida Municipal Solid Waste Leachates. M. WARD (1), G. BITTON (1), N.D. DENSLOW (2), AND T. TOWNSEND (1), Department of Environmental Engineering Sciences; (2) Protein Chemistry and Molecular Biomarkers Laboratory, University of Florida, Gainesville, FL 32611. The scientific community has recently directed its attention on the quest for determining the presence of hormonally active agents (HAA's) in the environment. Municipal Solid Waste (MSW) landfills may be a significant source of these HAA's, due to the composition of the waste. Landfill leachates are a complex mixture of organic and inorganic contaminants, some of which are known or suspected to be hormonally active. A recombinant yeast, *Saccharomyces cerevisiae*, containing the human estrogen receptor (hER) was utilized to assay for hormonal activity in MSW landfill leachates. Landfill leachates were collected from both active and closed cells at six landfill sites, across the State of Florida. The landfill leachates were not acutely toxic to the yeast cells. Our results show a detection limit of 4.2 ng/L for 17β-estradiol, which was used as the positive control in our assays. Our data show a relatively high degree of hormonal activity in the landfill leachates, ranging from 5 to 75 times greater than that induced by the positive control. Results indicate that sampling site, month, and strength of landfill leachate influenced the degree of hormonal activity.

2:45 PM AGR-10 Agri-Science Partnerships: Methods to Improve Instruction. M. A. WADE, Food and Resource Economics Dept., University of Florida, Indian River REC, 2199 South Rock Road, Fort

Pierce, FL 34945. Agricultural education has evolved from "watch-me-and-learn" to theoretical lecture to experiential learning. Subject matter has grown across discipline and national boundary, so new educational approaches must be examined that integrate the sciences and include those in education, industry and the public sector. This paper examines the formation of educational coalitions that become mutually inclusive groups of vested individuals with one goal or mission in common --- the transfer of knowledge and skill through interaction and hands-on experimentation. This symbiotic relationship must benefit all involved parties and provide students with a living laboratory. Students learn from those that are doing and by doing. This brings good science to life. This paper addresses the formation and development of educational coalitions or partnerships, diversity of membership, plan development, funding and infrastructure. Real coalitions are examined and discussed. Potential pitfalls and strategies for success are presented.

3:00 PM AGR-11 Preliminary Studies on *In Vitro* Procedures for the Biological Control of Cogongrass (*Imperata cylindrica* L.) O.U. ONOKPISE (1), J.G. ALDRICH (2) AND J. G. NORCINI (2). (1) Florida A&M University, Tallahassee, Florida 32307, and (2) University of Florida, IFAS, NFREC, Monticello, Florida 32344. Inter plant competition between native grass species - Gulf muhly grass (*Muhlenbergia capillaris;* MG) and Satin grass (*Pityopsis graminiflora;* PG) and the invasive species - Cogongrass (*Imperata cylindrica;* CG) was observed at the St. Marks National Wildlife Refuge, St Marks, Florida. As part of an on-going project, *in vitro* procedures were initiated to further understand the interaction among these grass species. Unhusked and dehusked seeds of MG, PG, and CG were surface sterilized and 4-5 seeds/petri-dish were plated on three separate solid media (i) Murashigie and Skoog basal medium (MS), (ii) MS medium plus 3 mg/L, 2,4-D (MS^+) and (iii) MS medium plus 0.3% phytagel w/v 1 mg/L of aminopurine, gibberellic acid, kinetin and 1ml/L of 5.2 uM zinc sulfate (SM). All media were adjusted to pH 5.8. Plated petridishes were incubated at 25°C for 16-hr photoperiod with light intensity of 40 uE and relative humidity of 35% for eight weeks. Harvested explants (root/shoot interfaces, rhizome tips, shoot internodes and root tips from CG, MG and PG were similarly plated on the same media and subjected to the same incubation conditions as for the plated seeds. For CG seeds, less than 25% germination was obtained for unhusked seeds whereas 100% dehusked seeds germinated. CG explants were not as successful as dehusked seeds with only 37% shoot growth resulting from explants. For MG, no germination was observed for unhusked or dehusked seeds. However, tissue growth resulted from leaf/root interface and new shoot of MG explants. PG seeds did not give any germination but tissue growth was observed on shoot tips grown on MS, MS^+ and SM media.

3:15 PM AGR-12 Effects of Citric Acid and Molasses in Stabilizing Fish Waste. J. JNO-BAPTISTE, M. ABAZINGE, O.U. ONOKPISE AND C. MCGOWAN, Florida A&M University, Tallahassee, Florida 32307. The disposal of copious amounts of processed waste generated by the seafood industry annually, has raised much environmental concerns. As a result, disposal in water bodies has been banned and landfilling is on the decline due to odor and ground water pollution problems. A Florida law mandating research on waste disposal alternative methods has resulted in efforts to stabilize seafood waste in order to eliminate odor before further research activities. Fish waste obtained from the Apalachicola Bay was subjected to concentrations of 3%, 5% and 10% citric acid and 10% molasses treatment performed in triplicates. Intensity of odor was determined over six weeks. It was found that the pungent decomposing odor of the fish waste was not completely eliminated, but very satisfactory results were obtained for the 10% molasses and citric acid additives. These treatment concentrations were therefore recommended for the seafood waste stabilization prior to further research activities.

3:30 PM BUSINESS MEETING: AGRICULTURAL AND NATURAL RESOURCES
MARK A. WADE, presiding

FAS POSTER SESSION (AGR)
FRIDAY, 9:30 AM – 4:00 PM
LEWIS FIRST FLOOR HALLWAY

POS -1 Consumer Attitudes and Food Safety. M. A. WADE, Food and Resource Economics Dept., University of Florida, Indian River REC, Fort Pierce, FL 34945.

ANTHROPOLOGICAL SCIENCES

FRIDAY 8:45 AM LEWIS 203
SESSION A
LINDA TAYLOR, UNIVERSITY OF MIAMI/KAREN WALKER UNIVERSITY OF FLORIDA, presiding

8:45 AM ANT-1 Disability and Anthropology: A Mutually Beneficial Relationship. DEANNA BARCELONA, Department of Anthropology, 4202 E. Fowler Ave., University of South Florida, Tampa 33620. In this paper, the relationship between anthropology and disability is explored through the summary of a two-year review of the literature. In this literature review, the broader connection between anthropological concepts, themes, methodology, and perspectives *and* disability studies is presented by loosely categorizing the work into four sections. After an introduction of anthropological contributions as a whole, the following sections are discussed: cultural anthropology, physical/biological anthropology and archaeology, linguistic anthropology, and applied anthropology. This research is part of a larger project that looks at the use of anthropology in decreasing the unemployment rate among people with disabilities. This aspect will be touched upon as part of the presentation.

9:00 AM ANT-2 Students With Disabilities and the Experience of College: A Comparative Ethnography, JUDITH A. ROSENBERG, University of South Florida, Department of Anthropology, SOC Room 118, Tampa Florida 33620. In Western culture, the period of transition from home to college marks a salient time for college students who have been identified as having a disability, as well as those who have not. This period allows for the first significant expression of independence and the making of major life decisions that will set the path for future career and life choices. A needs assessment was distributed to a total of 60 freshman college classes at two university settings, one a small liberal arts institution and the other a major research university. The content of the assessment examined the perceptions and basic knowledge of freshman students towards services available to them on campus. In addition, students were asked to identify as either having a disability or not having a disability. In contrast to university estimates, only 1% of the freshman college students identified themselves as having a disability, although all students had some knowledge of services for disabled students.

9:15 AM ANT-3 The American Cultural Basis for Scientific Racism: From Goddard to the Bell Curve and Beyond. V. GEIGER, P.O. Box 23000, Department of Sociology/Anthropology, University of Central Florida, Orlando 32816-1360. Scientific racism in America began in the early 1900s and has persisted for a century. The persistence of such an intellectual phenomena, including both the production and reception of an underlying ideology, requires a cultural basis. This paper explores scientific racism and its dependence on some basic aspects of American culture. In addition, I discuss how these same cultural phenomena are deliberately appropriated by scientific-racism advocates to further their cause.

9:30 AM ANT-4 The Other Side of the Tracks: Redevelopment in West Winter Park. AMANDA FRAZIER, Department of Anthropology, Rollins College, 1000 Holt Avenue Box 1498, Winter Park 32789-4499. Winter Park is a divided city. In the late 19th century, the railroad tracks running through the city served as a social, if not legal, barrier between blacks and whites. To the east of the tracks lived prosperous whites, and to the west lived black domestic workers. Winter Park remains largely segregated, across both race and class. The disparity in incomes and aesthetic appeal of the two sides of the tracks ignited city action to "clean up" the Westside beginning in the early 1990s. The City Commission approved a redevelopment plan in 1994—The City of Winter Park Community Redevelopment Area Plan (CRA). In the rhetoric of the plan and the reality of the redevelopment, social issues are treated as obstacles to be maneuvered around in route to economic expansion.

9:45 AM ANT-5 Feminist Witchcraft and Goddess Worship: Their Proliferation in the Late 20th Century. SARA BOOCKS, Department of Anthropology, 1000 Holt Ave., Rollins College, Winter Park 32789. Modern-day Feminist Witchcraft and the Goddess Movement have their roots in both the Wiccan beliefs of the past, and Feminist doctrines of the present. Their growth and proliferation in the late 20th century is compared as a response to patriarchal institutions and an answer to the spiritual needs of women. The relation of these religions to the Feminist Movement and Women's studies is revealed, as well as their core beliefs. Feminist Witchcraft and the Goddess Movement are examined in relation to power, sexuality, and social relations.

10:00 AM BREAK

10:15 AM ANT-6 Child Growth and Nutrient Adequacy on Nutrition Transition in the Tapebas of Ceará, Brazil. K. HJERPE, Department of Anthropology, University of Florida, Gainesville 32611. Most of the research examining nutrition in indigenous populations of Brazil focuses on Indians of the Amazon region. Little to no data are available on Indians of the Northeastern region who show more involvement in markets on acculturative processes in the way of social integration. I focus here on child growth in three Tapeba communities for analysis of gender and livelihood inputs on nutrition, showing that Tapeba children living in communities with greater income strategies on time allocation exhibit better growth and nutritional adequacy and that differences in growth were gendered in favor of females. Where access to income was less, mutual exchange on diet for labor was observed in food production practices and dietary compromises shaped to contribute to resource elasticity on which biological adaptation is met.

10:30 AM ANT-7 The Liminal State of Women's Status in Peru: Peru's Inability to Protect Women from Domestic Violence. LARISSA OWENS, Rollins College, 1000 Holt Ave, #2677, Winter Park, 32789. This paper evaluates the 1993 Peruvian Family Violence Law and its shortcomings. The Shining Path and the Presidency of Alberto Fujimori are examined in reference to the socio-political impact their programs have had on the view status and roles of women in the Peruvian culture. The impact of these forces is assessed in regards to how the significant contradictions in the Family Violence Law, new policies under Fujimori, and the lengthy violent conflict between government and Shining Path protagonists inhibit the successful implementation of policies that would make life safer for women in Peru in and outside the home.

10:45 AM ANT-8 Chilean Women and the Arpillera: The Transcendent Healing Function of Symbols in Action. C. JONES, Rollins College, 161 Mercado Ave., Orlando, 32807. When considering the issue of women's health in Latin America, most literature in the social sciences has focused solely on the issue of physical health, leaving the issue of psychological health largely unaddressed. In the spirit of recognizing a more holistic definition of "health," I will explore the specific psychological health of a group of women in Chile, living under the brutal dictatorship of Augusto Pinochet. The shared issues that brought them together, and the ways in which they found a measure of healing and reconciliation, show a close mirroring of the theories of Carl G. Jung. I will limit the context of my discussion to the activity at the *arpillera* workshops, the places where these women, known as *arpilleristas*, gathered to create embroidered wall hangings that told the stories of their suffering. The profound and positive impact that the workshops had on the lives of the women who participated in them suggest the usefulness of Jung's ideas in treating acute emotional trauma in a large group of society.

11:00 AM ANT-9 Environment, Resources, and Prehistoric Canoes: Preliminary Results of the 2000 Drought-Incited Excavations at the Newnan's Lake Canoe Site. D. L. RUHL (1) AND M. MEMORY (2), (1) Florida Museum of Natural History, PO Box 117800, Gainesville, FL 32611-7800, (2) C.A.R.L. Archaeological Survey, Bureau of Archaeological Research, Tallahassee, FL 32399-0250. The single largest cache of prehistoric canoes known in North America and possibly the world was discovered, recorded, and sampled from the Newnan's Lake Canoe site (8AL4792) in north central Florida during the summer drought of 2000 by the Archaeological Research Section of the Division of Historical Resources. Over eighty dugout canoes and canoe fragments were carefully located using GPS (Global positioning systems) methods, partially excavated, mapped, drawn, photographed, and measured. Fifty-three of these had samples taken from them for radiocarbon dating and wood analysis to age the canoes and ascertain what resources were exploited by the prehistoric people who made and used them. Ongoing research indicates that the majority of canoes are of *Pinus* sp., a southern hard pine, and dates range from @ 500 to 5,000 years ago. These findings will be compared to other known prehistoric canoes from around the state along with some discussion of the hypotheses (e.g., canoe yard, natural abandonment, drift, waterways and trade) that have emerged concerning such a large number of canoes from a single location.

11:15 AM ANT-10 Applications of the Original Public Lands Survey Records in Cultural-Historical Studies: Examples from Central and North-Central Florida. B. R. WHARTON, HDR, Inc., 2202 N. Westshore Blvd., Suite 250, Tampa 33607-5711. During the territorial and early statehood years of Florida, the current grid of townships and sections was first laid out by land surveyors employed by the U.S. General Land Office. The products of this survey (or the GLO survey), consisting primarily of field notes and township plat maps, provide the first systematic inventory of the natural and cultural resources of early Florida. This paper illustrates the utility of these records for locating archaeological sites (e.g., Indian mounds and stone-tool workshops) and Seminole War Period military and civil fortifications, early homesteads and settlements, bridges, Armed Occupation Act land claims and Spanish land grants, cultivated fields, Indian foot trails, and a variety of other cultural-historical resources. Because these features are spatially anchored to the township-section grid, their locations can be more precisely established with the aid of contemporary topographic, soils, and aerial photographs. Several examples of this conjunctive use of GLO survey data with contemporary maps are illustrated and discussed. The examples are drawn from the author's research in the Big Hammock region (Hernando and Pasco counties), Horse Creek (DeSoto County), Charlie Creek (Hardee County), Lake Hancock (Polk County), and Big Swamp (Marion County).

11:30 AM ANT-11 The Picnic Mound and Buck Island Revisited. L. D. COLLINS (1), R. J. AUSTIN (2), AND B. R. WHARTON (3), (1) University of South Florida, 4202 E. Fowler Ave., SOC 107, Tampa, 33620-8100, (2) Southeastern Archaeological Research, Inc., POB 2818, Riverview, 33568-2818, (3) HDR Engineering, 2202 N. Westshore Blvd., Suite 250, Tampa, 33607-5711. The Picnic Mound (8Hi3) and Buck Island (8Hi6) are significant Safety Harbor period burial mounds in Hillsborough County. Both are found in inland, riverine settings, the Picnic Mound near the South Prong of the Alafia River and Buck Island near the Hillsborough River. Originally investigated by Clarence Simpson under the auspices of the Works Progress administration in the late 1930s, these sites were among eleven that where later discussed in a 1952 monograph by Ripley Bullen. Both mounds contained numerous burials and ornate mortuary ceramics and contact-period artifacts. Examination of Simpson's original field notes, recently discovered mixed with other materials at the Smithsonian Institution, in combination with an analysis of known collections from these sites, has revealed new information regarding the mounds and their unique environmental settings. This paper presents the results of our research to date, which includes the relocation and mapping of the sites. Additionally, preliminary fieldwork conducted by the University of South Florida Archaeology Program adjacent to the Picnic Mound site has been conducted, as has a GPS survey of Buck Island.

11:45 AM ANT-12 Determining Form and Function: An Analysis of Use-Related Wear on *Strombus gigas* Shell Tools. E. D. PETERS, Department of Anthropology, 777 Glades Rd., Florida Atlantic University, Boca Raton, 33431. In pre-Columbian southeast Florida, the lack of viable lithic resources resulted in technological adaptations based upon shell tools. Queen conch (*Strombus giga*s) was commonly used because of its availability and morphological suitability. For this study, tool forms and functions were identified based upon morphological variation, evidence of use-wear, and comparative data. A functional typology was developed that can be used to classify *Strombus gigas* shell tools. This study demonstrates that shell tools exhibit patterns of wear that can be identified and examined using methods consistent with those employed in lithic analysis.

12:00 AM ANT-13 Maya Archaeology in the Puuc Region at Chac, Yucatan, Mexico. M. P. SMYTH, Department of Anthropology, 1000 Holt Ave 2761, Rollins College, Winter Park 32789-4499. The Puuc region of SW Yucatan was one of the leading areas of Maya civilization during the Terminal Classic period (AD 800-1000). Despite its significance to Maya prehistory, there is surprisingly little known about the time preceding the great cultural florescence. A long-term research program at the center of Chac is beginning to redress this shortcoming by providing extraordinary new information regarding the origins of the great Puuc hill cities. The finding of numerous early substructures at monumental and residential contexts, unusual mortuary practices, and various artifact remains showing central Mexican inspiration and/or origin has led to the serious realization that the center of Chac did not develop in cultural isolation. It is becoming increasingly evident that Teotihuacan played a significant role in the rise of urban centers in the Puuc region and elsewhere in northern Yucatan. This paper explores the evidence for foreign influences, contacts, or both during to the Early-Middle Classic periods (AD 300-650) at the Maya center of Chac. These data are transforming our understanding of the Maya hill region and its relationship to greater Mesoamerica.

FAS POSTER SESSION (ANT)
FRIDAY, 9:00 - 12:00 AM
LEWIS FIRST FLOOR HALLWAY

POS-1 GPS Survey of Indian Key (8Mo15): The Site as an Artifact. L. D. COLLINS. Department of Anthropology, 4202 E. Fowler Ave., SOC 107, Tampa, 33620-8100.

FRIDAY 2:30 PM LEWIS 203
SESSION B
LINDA TAYLOR, UNIVERSITY OF MIAMI/KAREN WALKER, UNIVERSITY OF FLORIDA, presiding

2:30 PM ANT-14 Coprophagy, Regurgitation, and Reingestion in Captive Lowland Gorillas at Miami MetroZoo. M. FARALDO AND L. WATSON, University of Miami, Department of Anthropology, PO Box 248106, Coral Gables 33124. There are three subspecies of gorillas: western lowland gorilla (*G. g. gorilla*), eastern lowland gorilla (*G. g. graueri*), and mountain gorilla (*G. g. beringei*). The entire captive population of gorillas is the lowland gorilla, however most field data focus on the mountain gorilla. There is a growing body of data on wild lowland gorillas. which we will use for comparisons. Today I present data on these behaviors taken from a larger study by L. Watson, "Cross-environmental behavioral study of western lowland gorillas." Focal animal samplings were used to gather frequency data on coprophagy, regurgitation, and reingestion - behavior seen in wild and captive groups. Results were compared with those recorded on free-living gorillas. Any observations of coprophagy, regurgitation, and reingestion may indicate changes in the animals' response to environmental stress, or lack thereof, particular to Florida's environment.

2:45 PM ANT-15 A Lemur Reserve in Manatee County: Phase I. B. A. GROSSI AND P. BODRY-SANDERS, Lower Primate Conservation Foundation, P.O. Box 249, Myakka City, 34251. Founded in 1996, The

Lower Primate Conservation Foundation maintains "no room in the ark" prosimian species, i.e., those that are not the charismatic megafauna often used to attract public interest and funding, but those that should be protected for their inherent value and their significance to understanding primate evolution and ecology. The 90-acre reserve contains a variety of habitats. Thirteen lemurs (5 *Eulemur fulvus rufus*, 2 *E. mongoz*, 3 *Lemur catta*, 3 *Hapalemur griseus*) live in an outdoor 13-acre fenced enclosure surrounded by an electrified fence within a 77-acre buffer zone. An outreach program is available for schools. A field training program in behavioral ecology is planned.

3:00 PM ANT-16 Spina Bifida, Osteoarthritis, and Enamel Hypoplasia: Reconstructing the Pathology of a Modern Chinese Teaching Skeleton. P. M. DIETRICH, Department of Anthropology, 102 Merrick Bldg., University of Miami, Coral Gables 33124-2005. Available data on a human male skeleton purchased for forensic and physical anthropology courses at the University of Miami, consisted solely of the country of origin, China, and the terminus ante quem, circa 1890's. The skeleton revealed a congenital neural tube defect known as spina bifida, to an extent that adversely affected walking, and enamel hyplasia, indicating inadequate nutrition during childhood. Yet it also demonstrated a form of osteoarthritis known as activity-induced arthritis, and severe (>15 sq cm) eburnation of articular facets in both knees and elbows, with the left side being the more affected. The pathologies along with several other findings of note, their interpretations, and their implications about the life and livelihood of this male have been investigated and are presented.

3:15 PM BUSINESS MEETING: ANTHROPOLOGICAL SCIENCES
KAREN WALKER/LINDA TAYLOR, presiding

ATMOSPHERIC AND OCEANOGRAPHIC SCIENCES

FRIDAY 10:30 AM LEWIS 207
SESSION A

SPECIAL SESSION

Biogeochemical Studies in Florida Bay, the Everglades and their watersheds

Joint Session of the Atmospheric and Oceanographic Sciences Section
and the Environmental Chemistry and Chemical Sciences Section

(see pages 32 – 35 for abstracts)

FRIDAY 2:30 PM LEWIS 303
SESSION B
JOHN TREFRY, FLORIDA INSTITUTE OF TECHNOLOGY, presiding

2:30 PM ATM-1 Study Design for the Determination of NO_x to HNO_3/NO_3^- Transformation Rates in a Coastal Environment. K. L. KENTY and N. D. POOR, University of South Florida, USF COPH EOH MDC-56, 13201 Bruce B. Downs Blvd., Tampa 33613. The Tampa Bay Estuary receives 29% (Zarbock, *et al.* 1996) of its total annual nutrient loading from wet and dry atmospheric deposition. Stationary and mobile combustion sources emit NO_x, resulting in formation of the more soluble HNO_3/NO_3^-. While NO_x emission rates from large stationary sources are measured, inventories from mobile sources are indirectly estimated and have large uncertainties. Additionally, atmospheric processes govern transformation rates more than emissions rates, which can be troublesome for estuarine management as the development of effective ambient nitrogen control strategy requires the knowledge of nitrogen deposition source apportionment. This paper presents a research plan and design for the determination of NO_x to HNO_3/NO_3^- transformation rates in a coastal environment and to validate Tampa's mobile source emissions inventory.

2:45 PM ATM-2 Ecological Distribution and Antibiotic Resistance of Pathogenic Vibrionaceae present in Tampa Bay. JOHN PISCIOTTA AND, JODY HARWOOD. Dept. of Biology, Univ. of South Florida, Tampa, 33620-5150. While pathogenic *Vibrio* spp., associated with shellfish poisoning are known to exist within Tampa Bay, little is know regarding ecological distribution and antibiotic resistance patterns. Even less is known of the possible selective effect of wastewater outfalls on antibiotic resistance. Impetus provided by the rapid growth of Florida shellfishing, these questions were addressed. Culturable heterotrophic bacterial isolates were recovered from sediment and water samples acquired from sites situated around Tampa Bay. The proportion of total Vibrionaceae (TCBS+), and total antibiotic resistant isolates at each site was examined over the course of 14 weeks via replica plating. TCBS+ isolates were next picked for biochemical and physiological identification. Vibrionaceae resistance to co-trimoxazole was significantly greater in sediments adjacent to a wastewater treatment outfall site compared to a non-impacted control site.

3:00 PM ATM-3 Contaminants in a NE Florida Estuary: Effects of Causeways and Spoil Piles. S. L. FOX (1), C. L. MONTAGUE (1), D. L. HYDORN (2), AND K. J. SULAK (3), (1) Univ. of Florida, Gainesville 32611-6450, (2) Mary Washington College, Fredericksburg, VA 22401, (3) USGS, Gainesville 32653. The Timucuan Ecological and Historical Preserve is a 46,000-acre salt marsh estuary located between the mouths of the St. Johns River (SJR) and the Nassau River in NE Florida. Alterations to the system along the SJR include causeways, bridges, spoil piles and canal (ICW) construction. Sediments that collected behind causeway impoundments, due to decreased tidal velocity, were tested for contaminants (PAHs and heavy metals) in anticipation of restoration efforts. Sediments from sites closed off from direct tidal flow with the SJR (by causeways) were less contaminated than sediments from either the SJR or from sites adjacent to bridges. Sediments from sites adjacent to spoil piles were the most contaminated in this study.

3:15 PM ATM-4 Simulation of a Coral Reef Environment in Salt Water Aquaria. AARON M. SMITH, Dept. of Biology, Palm Beach Atlantic College, P. O. Box 24708, West Palm Beach, FL 33416. Until recently, more attention has been given to maintaining coral reef vertebrates in marine aquaria than maintaining the invertebrates. Today, in addition to the vertebrates, many marine aquaria also contain mollusks, cnidarians, echinoderms, arthropods, and worms. This presentation will outline the products and procedures needed to maintain these invertebrates. Topics to be covered will include (1) intensity and frequency of lighting, (2) type of water, salinity levels, and needed chemical elements, (3) types of filters and how they operate, (4) the proper water temperature to be maintained, (5) correct substrates, and (6) feeding procedures for the various animals. It will be shown that most of these parameters vary according to species.

3:30 PM BREAK

3:45 PM ATM-5 Satellite Beach Coastal Amelioration and Habitat Development. SANDY S. CARNIVAL, AND TIMOTHY G.RILEY, Rollins College Brevard, Dept. of Environmental Studies, 475 South John Rhodes Blvd., West Melbourne, FL 32904-1009. Increased population numbers in Florida offer challenges to land managers in terms of coastal habitat fragmentation. Through the efforts of concerned citizens and legislators, the Preservation 2000 and Florida Communities Trust programs have provided the means by which local municipalities are able to secure critical parcels of these shrinking ecosystems for conservation projects. As students of environmental management and interns with the City of Satellite Beach, Florida, we took on the task of creating both long-term vegetative and burn management plans in managing for the needs of the southeastern beach mouse and gopher tortoise. This paper will address the realities of developing such a plan and the further prospects for the plan's implementation.

4:00 PM ATM-6 Sediment Deposition in the Shelikof Strait, Alaska. ROBERT D. REMBER and JOHN H. TREFRY. Department of Marine & Environmental Systems. Florida Institute of Technology, Melbourne, FL, 32901. The Shelikof Strait is located between the Alaskan Peninsula and Kodiak Island. The primary source of sediment is the Susitna-Knik-Matanuska River system with a combined drainage area of ~60,000 km^2. These glacial rivers transport ~60-80 MT of suspended sediment to the study area each year. Sedimentation rates range from 0.24 cm/y in northern Shelikof Strait to 1.0 cm/y in the southern strait. Several cores from the southern Shelikof Strait provide evidence that the amount of sediment delivered to this area has at least doubled during the past 20-30 y. The doubling of sediment accumulation rates in some cores dates back to ~1980 and may be related to increased glacial retreat.

4:15 PM ATM-7 Removing Organic-Rich Sediment from Coastal Florida Environments. JOHN H. TREFRY. Department of Marine & Environmental Systems, Florida Institute of Technology, Melbourne, FL 32901. Thick layers of fine-grained organic-rich sediment have been identified throughout the coastal zone of Florida during the past several decades. Such sediment harbors contaminants, alters benthic habitats and promotes enhanced turbidity and decreased light penetration. As part of a proposed long-term effort, so-called muck sediment has been recently dredged from two creeks along the east coast of Florida. In each case, the creek was full of muck that was poised to spread to the adjacent Indian River Lagoon and coastal Atlantic Ocean. This cleaning of a “filter” for the lagoonal system has clearly circumvented the more difficult task of dredging a more expansive area of the lagoon and improved navigation in each creek. However, the influence on water quality and sediment environment requires some detailed study to demonstrate.

4:30 PM BUSINESS MEETING: ATMOSPHERIC AND
OCEANOGRAPHIC SCIENCES
JOHN TREFRY, presiding

BIOLOGICAL SCIENCES

FRIDAY 9:00 AM LEWIS 205
SESSION A
HOWARD LEVINE, DYNAMAC CORPORATION, presiding

9:00 AM BIO-1 Some approaches to the estimation of the stability of functioning closed ecological systems. V. YE. RYGALOV (1)

AND T. W. DRESCHEL (2). (1) University of Florida, Gainesville, FL and (2) The Dynamac Corporation, Kennedy Space Center, FL 32899. Natural and artificial Closed Ecological Systems (CES) function on the basis of closed cycles of matter transformation. In the estimates of the stability of closed matter cycles there are three distinguishing aspects: the stability of the engineering of the physical system's operation; the stability of the functions of the biological links; and the stability of the closed biophysical cycle pertaining to the transformation of matter. The human factor, which reflects the level of understanding of the mechanisms of CES function, and is realized by active control of processes in the system, can readily increase the stability of the operation of a Closed Ecosystem. In this paper we propose some theoretical approaches to control which include a mathematical description of CES stability.

9:15 AM BIO-2 The Provision of Nutrients to Wheat Plants Grown on a Porous Tube Nutrient Delivery System Using a Fibrous Ion Exchange Resin Substrate. G. K. TYNES (1), T. W. DRESCHEL (1), H. KASAHARA (2) AND H. G. LEVINE (1), (1) The Dynamac Corporation, Kennedy Space Center, FL 32899, (2) Hokkaido Tokai University, Hokkaido, Japan. A plant germination material known as the Fibrous Ion Exchange Resin Substrate (FIERS) was assessed for its ability to provide nutrients to plants growing hydroponically on a porous tube nutrient delivery system. Nutrient providing substrates that only require the addition of water simplify plant culturing in space and reduce the risks of corrosion and the formation of precipitates throughout the system. Seeds were imbibed and grown on six porous tubes; three at different wetness levels utilizing only the FIERS and three at comparable wetness levels using a quarter-strength Hoagland's nutrient solution. The FIERS was successful in supporting plant growth through seed production. This effort is in support of NASA proposal 98-HEDS-01-036.

9:30 AM BIO-3 A ground-based test bed for evaluating plant remote sensing technologies. T. W. DRESCHEL, T. FOSTER, AND C. R. HALL, The Dynamac Corporation, Mail Code: DYN-1, Kennedy Space Center, FL 32899. The need to remotely monitor and map plant moisture content has been highlighted recently by repeated extensive and costly outbreaks of wildfires. Remote detection of moisture in canopies is made difficult by the interactions between the soil-vegetation-atmosphere moisture gradient. We have developed a test bed utilizing a technology being developed for growing plants in space and have been evaluating a remote sensing system for its ability to detect small differences in plant leaf water content. Hyperspectral signatures and other measurements of plant health are used to determine plant water status and photosynthetic and transpiration rates. Measurements indicate that transpiration rate, photosynthesis, and leaf moisture content can be affected over a short period by adjusting the root moisture potential. This effort is supported under NASA contract NAS10-12180.

9:45 AM BIO-4 Water-use efficiency of twelve species in the Florida scrub. T.E. FOSTER (1) and J.R. BROOKS (2), (1) Dynamac, Mail Code: DYN-2, Kennedy Space Center, FL 32899, (2) Environmental Protection Agency, Western Ecology Division, 200 SW 35th St, Corvallis, OR 97333. Florida scrub is a relict ecosystem confined to the inland sand ridges and coastal dunes of Florida. Due to the xeric nature of scrub, a plants ability to conserve water may be vital to its survival. This study examines how efficient twelve species in fire maintained scrub are in their water-use and whether land management practices have an effect on a species' water-use efficiency. In fire maintained scrub, the most water-use efficient species comprise the evergreen oaks *Quercus geminata*, *Quercus chapmanii*, *Quercus myrtifolia*, along with the vines *Galactia elliottii* and *Smilax auriculata* and the saw palmetto (*Serenoa repens*). Most species responded similarly between fire maintained and mechanically treated scrub. However differences were evident in the fire-suppressed scrub, for example Q*uercus chapmanii* was more water-use efficient while *Galactia elliottii* was less water-use efficient.

10:00 AM BIO-5 Survival and Growth of Scrub Species Planted in a Former Agricultural Site. P.A. SCHMALZER (1) AND F.W. ADRIAN (2), (1) Dynamac Corporation, DYN-2, Kennedy Space Center 32899, (2) Merritt Island National Wildlife Refuge, P.O. Box 6504, Titusville 32782. Scrub vegetation reestablishes poorly where it has been eliminated. In a pilot project, scrub oaks, saw palmetto, and other species were planted in a 5.6 ha former citrus grove on scrub soil adjacent to extant scrub. Oaks, 1-year-old tublings, (*Q. chapmanii, Q. geminata, Q. myrtifolia*) were planted in the summer of 1992 with a second planting in the summer of 1993. *Serenoa repens* and other scrub species (1-gallon pots) were planted in the summer of 1993. We marked 150 oaks from the first planting, 50 from the second, and 34 saw palmetto. We relocated these plants annually and determined survival and height growth. Mortality of oaks was concentrated in the first year. Survival and growth of *Q. geminata* were significantly greater than *Q. chapmanii/Q. myrtifolia*. Initial survival of *Serenoa* was high but declined due to rooting by feral hogs. *Serenoa* grew slowly.

10:15 AM BIO-6 Modular Interpretation of Architecture in Shrub Species of Patagonia: Winter Growth Case Study. D. N. RAGOONATH (1), J. A. GAMORY (1), AND A. M. BEESKOW (2). (1) Barry University, 11300 N.E. 2nd Ave, Miami, 33161, (2) Universidad Nacional de la Patagonia, San Juan Bosco, Puerto Madryn. The winter growth patterns of eight shrubs in N.E. Patagonia were studied: *Chuquiraga avellanedae, Acantholippia seriphioides, Berberis heterophylla, Lycium chilense, Larrea divaricata, Schinus johnstonii, Larrea nitida* and *Condalia microphylla.* The basic modules examined were brachyblasts, dolycoblasts, thorns and flowers. Leaves per shoot, apical and axillary buds were also counted. Ten shoots (10 cm) were cut from each plant. All tall species had brachyblasts and dolycoblasts. *A. seriphioides* was the only short species to have both brachyblasts and dolycoblasts. *L. nitida* and *A. seriphioides* showed the most growth activity. The results will be used as a preliminary investigation for the year round conservation of the species studied. (Supported by NIH-FIC MIRT Grant, TW00033-07, Barry University).

10:30 AM BREAK

10:45 AM BIO-7 Florida Scrub Jay fledgling survival and cause-specific mortality. M. L. LEGARE AND D. R. BREININGER, The Dynamac Corporation, Mail Code DYN-2 , Kennedy Space Center, Florida, 32899. The Florida Scrub Jay *(Aphelocoma coerulescens)* is our only endemic avian species and is threatened with extinction along the Atlantic coast. Previous studies have indicated that Florida Scrub Jay fledglings encounter high predation, but have not adequately determined the specific predators responsible for fledgling mortality. We radio tagged 15-day old Florida Scrub Jay nestlings (n = 45) using 0.8 g radio transmitters attached to an aluminum leg band. We identified avian, mammalian, and reptilian predators. In addition, we documented mortality events without predation. The Mayfield estimate of daily survival probably was 0.9388 (95% C.I. = 0.9118, 0.9659), (n = 24). In 1999, five radio tagged fledglings (20.8%) survived the 3-week post-fledging period. The survival estimate for the 21-day period was 0.197. In 2000, the Mayfield estimate of daily survival was 0.9658 (95% C. I. = 0.9446, 0.9870), with a 21-day period survival estimate of 0.319.

11:00 AM BIO-8 Recent Water Quality Trends in Hillsborough Bay, Florida and the Apparent Response in Seagrass Expansion. J.O.R. JOHANSSON, City of Tampa, Bay Study Group, 2700 Maritime Blvd., Tampa 33605. The City of Tampa has conducted detailed field surveys of seagrass expansion in Hillsborough Bay since 1986. This information combined with water quality monitoring by both the Hillsborough County Environmental Protection Commission and the City of Tampa has been used to search for potential relationships between seagrass expansion and water quality trends. The expansion of seagrass that started in the mid 1980s in Hillsborough Bay apparently resulted from the large decrease in eutrophic state that occurred in the early 1980s. However, recent high rainfall amounts during the years 1995, 1996, and the 1997-1998 El Nino event may have contributed to a reduction in seagrass expansion. Ambient nitrogen concentrations, phytoplankton biomass, light attenuation, and color content all increased during this period of high rainfall.

11:15 AM BIO-9 Trends in Submerged Aquatic Vegetation in Hillsborough Bay, Florida. W. M. AVERY, City of Tampa, Bay Study Group, 2700 Maritime Blvd., Tampa, FL. 33605. Since 1986, the City of Tampa has monitored two species of seagrass, *Halodule wrightii* and *Ruppia maritima*, and the attached alga, *Caulerpa prolifera*, in Hillsborough Bay. *H. wrightii* areal coverage expanded from 0.2ha in 1986 to about 56ha in 1997. *H. wrightii* coverage remained near 56ha between 1998-1999, however, areal coverage increased during 2000 as extensive recolonization in western Hillsborough Bay was documented. *R. maritima* areal coverage has fluctuated between 2-40ha but has recently become a minor component of seagrass composition in Hillsborough Bay. Two *C. prolifera* areal coverage peaks of 280ha and 190ha were recorded in western Hillsborough Bay during 1988 and eastern Hillsborough Bay during 1990, respectively. Each peak was followed by a rapid decline of coverage with no *C. prolifera* presence noted in Hillsborough Bay after 1996.

11:30 AM BIO-10 Minimum Wetland Water Levels to Prevent Significant Harm to Cypress Wetlands in the Northern Tampa Bay Area. T. F. ROCHOW, Southwest Florida Water Management District, 2379 Broad St., Brooksville, FL 34609. The Northern Tampa Bay (NTB) area covers major portions of several counties in west-central Florida. Since the 1930s, increasing groundwater withdrawals, mostly from the Floridan aquifer, have caused a lowering of water levels in wetlands that has adversely impacted wetland health. Recently the Southwest Florida Water Management District (SWFWMD) has been working on Minimum Water Levels to prevent significant harm to isolated cypress stands. Analysis indicates that median water levels over a six year period that are no more than 1.8 feet below cypress "Normal Pool" levels will prevent significant harm to this wetland type. Actions are being taken by SWFWMD, Tampa Bay Water, and local governments to reduce water demand and bring on new water supply sources that are expected to improve wetland water levels in the NTB area in the future.

11:45 AM BIO-11 Range Expansion and Colonization of the Green Mussel, *Perna viridis*, along Florida's West Coast. DEBRA A. INGRAO

(1), AMY J. BENSON (2), AND MARC A. BLOUIN (3), (1) Mote Marine Laboratory, 1600 Ken Thompson Parkway, Sarasota, FL 34236, (2) U.S.G.S., Florida Caribbean Science Center, 7920 NW 71st Street, Gainesville, FL 32653, (3) U.S.G.S., Great Lakes Science Center, 1415 Green Road, Ann Arbor, MI 48105. The Indo-Pacific green mussel, *Perna viridis*, was discovered in two Tampa Bay power stations in 1999. The largest *P. viridis* (109.8 mm. in length) was found in December 1999 in Tampa Bay, which could date the introduction back to at least September 1998. *Perna viridis* specimens as small as 15 mm in length were sexually mature. During a limited survey in July 2000, *P. viridis* was discovered outside of Tampa Bay in the Gulf of Mexico from the island of Boca Grande to the south, and north to Johns Pass between Treasure Island and Madeira Beach. This data suggest the initial point of introduction was in the vicinity of the Port of Tampa.

FRIDAY 2:30 PM LEWIS 205
SESSION B
CARLTON HALL, DYNAMAC CORPORATION, presiding

2:30 PM BIO-12 Goals of The Southwest Florida Regional Ambient Monitoring Program (RAMP). K. HENNENFENT (1) AND R. BROWN (2). (1) City of Tampa, Bay Study Group, 2700 Maritime Blvd., Tampa 33605, (2) Manatee County Environmental Management Department, P.O. Box 1000, Bradenton 34206. The Southwest Florida Regional Ambient Monitoring Program, RAMP, was formed as regional governmental agencies united to combine strategies to meet the natural resource management goals set forth by the Tampa Bay Estuary Program and the Sarasota Bay Estuary Program. RAMP has established a comprehensive regional ambient monitoring program, standardization of methodologies and sampling protocols and laboratory quality assurance evaluations. Due to state and federal representatives requesting the recommendations of RAMP on policies, procedures and program objectives for implementation into regional and state programs, a more formal position on the issues is being established.

2:45 PM BIO-13 Decreasing Trend of Macro Algae in Hillsborough Bay. JOHN J. PACOWTA, City of Tampa, Bay Study Group, 2700 Maritime Blvd., Tampa 33605. Hillsborough Bay is found in the north east end of Tampa Bay and is the section of Tampa Bay that receives most of the nutrient rich run off that feeds the bay. Large amount of macro algae is an indicator of poor water quality and the presence of high nutrients. The City of Tampa has been monitoring macro algae in

Hillsborough Bay since 1985 using five fixed transects. During the fifteen years of monitoring we have seen the biomass of macro algae drop to almost zero reflecting the improving trend of water quality in this section of Tampa Bay. Data showing the relationship between water quality parameters and the annual average amount of macro algae found in the bay will be presented.

3:00 PM BIO-14 The Composition of Benthic Infauna in Hillsborough Bay, Tampa Florida from 1996-2001. GENE PINSON, City of Tampa, Department of Sanitary Sewers, Bay Study Group, 2700 Maritime Blvd., Tampa 33605. The benthic community is an important indicator of changes in the quality of the surrounding waters and sediments. Hillsborough Bay is the northeastern arm of the "Y" shaped Tampa Bay estuary and has historically been the most degraded segment of the Bay system. Hillsborough Bay has been significantly abused for decades through excessive nutrient addition from point and non-point sources, However, improvements in many biological parameters have been documented in Hillsborough Bay as a result of regulations and awareness of environmental concerns. This discussion will compare temporal trends from the benthic infaunal community from 1996 to 2001.

3:15 PM BIO-15 The Life History of the Parasitic Isopod *Glossobius hemiramphi* (Isopoda: Cymothoidae) and its Relationship to its Host *Hemiramphus brasiliensis* (Pisces: Hemiramphidae.) M. BAKENHASTER (1), R. S. MCBRIDE (1), AND W. W. PRICE (2), (1) Florida Fish & Wildlife Conservation Commission, Florida Marine Research Institute, 100 8th Ave. SE, St. Petersburg 33701, (2) Univ. of Tampa, Dept. of Biology, 401 W. Kennedy Blvd., Tampa 33606. This study documents relatively high infestation rates of the isopod *Glossobius hemiramphi* on *Hemiramphus brasiliensis*, a valuable baitfish harvested in south Florida. A sample of 2996 *H. brasiliensis* collected year-round between Palm Beach and Key West had an average infestation rate of 10.3%. Infestation rates were examined with respect to season and host size class. Isopods occurred in the oral-branchial cavity of the host, primarily as single male-female pairs. Embryos present within the brood pouch of female isopods were divided into five ontogenetic stages. A complete life cycle of the parasite has been proposed.

3:30 PM BREAK

3:45 PM BIO-16 Recent Additions to the Mayflies (Insecta: Ephemeroptera) of Tennessee And Discussion of Endemic Species of the Central Basin. LEWIS S. LONG AND JAMES P. CUDA, Department of

Entomology and Nematology, University of Florida, Gainesville 32611. The mayfly fauna for the state of Tennessee is presented, with 143 species in 43 genera and 15 families. Unpublished collection records now bring the total to 157 species in 45 genera. More surveys for the state are necessary due to the fact that only 17 counties (18%) have records of more than 10 species, 48 counties (51%) have less than 10 species and 30 counties (31%) have no records for mayflies at all. Overall, mayfly diversity in Tennessee is only second to North Carolina (182 species) and the composition more similar to that of Virginia and North Carolina than that of other southeastern states. Surveys in the central portion of the state have revealed the presence of several endemic species from the Central Basin portion of the Interior Low Plateau physiogeographic region.

4:00 PM BIO-17 A New Species of *Ercolania* from the Florida Keys (Opisthobranchia: Ascoglossa: Limapontiidae). D. C. GONSALVES-JACKSON, Department of Biological Sciences, Florida Institute of Technology, Melbourne 32901. A new species of *Ercolania* from Key Largo, Florida is described. This species is found with its algal food, *Cladophoropsis* sp. associated with roots of the red mangrove, *Rhizophora mangle* and on the lagoon floor. A comparison with other *Ercolania* species from Florida is made. This species is unique from other *Ercolania* species by its numerous cerata of varying sizes, bright green coloration, vein-like pattern at the base of the rhinophores, and Type 2 (lecithotrophic) developmental pattern.

4:15 PM BIO-18 The Influence of Altered Hydrology on the Population Distribution of Two Species of Hermit Crab (*Clibanarius vittatus* and *Pagurus maclaughlinae*) in the Indian River Lagoon System, Brevard County, Florida. C.J. KELLY AND R.L. TURNER, Florida Institute of Technology, 150 W. University Blvd., Melbourne 32901. Present population distributions of *Clibanarius vittatus* and *Pagurus maclaughlinae*, two species of hermit crab commonly found in the Indian River Lagoon system, are compared to the distribution of these two species reported by Grizzle (1974) as *C. vittatus* and *P. bonairensis*. Based on historical and present hydrological data obtained from the Florida Department of Environmental Protection, hydrology of the lagoon has changed markedly, especially during a period of low salinity in the middle and late 1990s. Sampling at 8 of Grizzle's 52 stations so far has revealed little change in the distribution of the two species over the last 30 yr.

4:30 PM BIO-19 Wing-loading and Minimum Flight Temperature in Cicadas (Homoptera: Cicadoidea). CAROLINA G. VALDES, AND ALLEN F. SANBORN, School of Natural and Health Sciences, Barry

University, Miami Shores 33161. Previous cicada studies have demonstrated some relationships between habitat and the minimum body temperature necessary to produce a controlled flight. However many species do not follow these simple relationships. Any flying animal must produce sufficient lift in order to remain airborne. Theoretically animals with lower wing-loading (greater wing area for a given body mass) should require a lower frequency of flight muscle contraction in order to produce the necessary lift to generate flight. This suggests minimum flight temperature should increase proportionally with wing-loading since muscle contraction kinetics are temperature dependent. With this study we analyze both intraspecific (in *Magicicada* spp.) and interspecific relationships of wing-loading and the ability of the cicadas to fly. Analyses show that wing morphology (wing area and wing loading) scales to body size as predicted by geometric similarity. However, neither wing area nor wing loading correlate to minimum flight temperature. Wing length is the only morphological measurement that correlates to minimum flight temperature.

4:45 PM BIO-20 Descriptive Analysis of the Calling Songs of Some North American Cicadas (Homoptera: Cicadoidea). ALICE CIOARA AND ALLEN F. SANBORN, School of Natural and Health Sciences, Barry University, Miami Shores 33161. Most male cicadas produce an acoustic signal to attract a mate. The sound pulses are generally produced when muscles buckle a chitinous membrane, the timbal, at the base of the abdomen. The sound pulses are then modified by several body components to produce the characteristic sounds of the calling songs. The songs of individual species must be sufficiently different to act as a reproductive isolating mechanism. We analyze here the calling songs of several North American cicadas. The frequency and temporal characteristics of songs from species in the cicada genera *Cornuplura*, *Diceroprocta*, *Okanagana*, *Okanagodes*, *Pacarina*, and *Tibicen* will be described. Analysis shows that song frequency scales with body mass as would be predicted. Comparisons of calls produced by species within the same environment show the acoustic parameters differ supporting the reproductive isolating mechanism function of the calls. If two species of similar size inhabit the same area, there is a greater difference in the temporal parameters of the calls as call frequency is a product of the physical components of song production.

5:00 PM BIO-21 A Study of the Juvenile Finfish Population Dynamacs of Matanzas Inlet, Florida. CAROLE LYLE DEMORT, University of North Florida, Jacksonville, FL. For a three year period, from 1996-1998, the juvenile finfish populations were studied in Matanzas Inlet on the East Coast of Florida. Until 1999, the Matanzas Inlet had remained the last natural inlet on the Atlantic Coast of Florida, basically unchanged by man since before the time of the Spaniards. Fish collections were made on a biweekly basis using a combination of seines, cast nets, modified otter trawls, and plankton nets. Basic water analyses were conducted at the time of the collections. The fish were measured for size, body condition, and a random subset were set aside for later analysis of stomach contents and internal conditions. A total of 115 species were collected over the three-year period. Striped mullet, spot, silver jenny, striped killifish, tidewater silversides, striped anchovy, Atlantic menhaden, spotfin mojarra, and pinfish remained consistently among the top twenty species and showed relatively consistent seasonal changes during the study. Another group of species including bluefish, Spanish sardine, sheepshead porgy, Florida pompano, permit, longnose killifish, bay anchovy, pigmy filefish, and the black-cheeked tonguefish, showed wide fluctuations in population dynamics seasonally and annually.

5:15 PM BUSINESS MEETING: BIOLOGICAL SCIENCES
THOMAS W. DRESCHEL, presiding

COMPUTER/MATHEMATICAL SCIENCES

FRIDAY 10:30 AM LEWIS 305
SESSION A
JACCI WHITE, SAINT LEO UNIVERSITY, presiding

10:30 AM CMS-1 How Computers can affect Attitude in a Mathematics Classroom. JACCI WHITE, Department of Mathematics and Sciences MC-2199. Saint Leo University. 33701 St. Rd. 52, Saint Leo 33574. This presentation illustrates the results of a statistical study conducted to determine the affect that different formats of computer use in the mathematics classroom can have on student attitudes. Computer usage for instruction ranged between Academic Systems as the sole form of instruction, supplemental student activities on the computer, and no computer access at all. Attitude towards mathematics was the only outcome that showed change at a statistically significant level.

10:45 AM CMS-2 How to Use Group Representations to Express the Multilinear Identities of an Algebra. SIAMACK BONDARI. Saint Leo University, Saint Leo, FL 33574. Let R be an algebra over a field ϕ of characteristic zero or large enough prime. A polynomial $f(x_1, x_2, \ldots, x_n)$ is said to be a polynomial identity of R if

$f(x_1, x_2, \ldots, x_n) = 0$ for all $x_1, x_2, \ldots, x_n \in R$. A multilinear identity of degree n is an identity of the form $\sum_{\pi \in S_n} \alpha_\pi [x_1 . x_2 . \ldots . x_n]_\pi$ for some numerical coefficients $\alpha_\pi \in \phi$. Since the symmetric group of n objects S_n has $n!$ elements, to find an identity of degree n we need to find $n!$ coefficients which could be a very tedious task. Fortunately, the above polynomial can be represented by the group ring element $\sum_{\pi \in S_n} \alpha_\pi \pi$. The theories of group representations can be used express each identity as a linear combination of the basis elements in that degree, one should be able to write each multilinear identity as a sum of identities, which reduces the number of coefficients that need to be computed.

11:00 AM CMS-3 Using Group Representations and Computer Algebra to Process the Identities of degree n a Given Algebra. SIAMACK BONDARI. Saint Leo University, Saint Leo, FL 33574. A multilinear identity $\sum_{\pi \in S_n} \alpha_\pi [x_1 . x_2 . \ldots . x_n]_\pi$ of degree n with numerical coefficients α_π from some field of characteristic zero or large enough prime ϕ can be represented by the group ring element $\sum_{\pi \in S_n} \alpha_\pi \pi$. Then the group representation theory can be used to express each identity in terms of the basis elements of the group ring. The procedure described in this talk has two advantages over the techniques used in the past. First of all, it simplifies the problem by reducing the number of the unknown coefficients of an identity of degree n from $n!$ to the dimension of the subring under discussion. Secondly, it computes a basis for the identities and therefore gives all the identities of a given degree. It should be noted that the technique is highly computational and requires knowledge of computer programming.

11:15 AM BREAK

11:30 AM CMS-4 The Trapper Tracker. CAYETANO LANDEROS, Saint Leo University, Saint Leo, FL 33574. The Trapper Tracker is a computer program specifically designed to aid in the registration of members and users of a gun range but can be used for any similar operation. The program replaces a completely manual registration process for controlling the members and shooters who utilize the range. The previous manual system caused delays in registration and loss of applications. Through the use of a completely integrated database, the system will keep track of a number of items such as: personal information, email list, shooting records, scores, etc. As well as introducing a database for storage of the data, an Active Server Page (ASP) has been created to allow applicants to register online. With ASP, management has the technology to allow applicants to enter data into the appropriate fields of the database. This system provides the range with state of the art technology with the latest in data management and retrieval. The program is a presentation of the program demonstrating its capabilities.

11:45 AM CMS-5 Introduction to the Open System Interconnection (OSI) model. SHANE METZLER, 33701 State Road 52, MC#3555 Saint Leo University, Saint Leo, Fl. 33574. A brief introduction to the ANSI standard Open System Interconnection model, which consists of seven layers: physical, data link, network, transport, session, presentation and application layers. The function of each layer will be described in detail and how they communicate with each other. Also a brief comparison of the OSI model and the TCP/IP Protocol will be discussed.

FRIDAY 2:30 PM LEWIS 305
SESSION B
JACCI WHITE, SAINT LEO UNIVERSITY, presiding

2:30 PM CMS-6 Fibonacci in the Classroom. LI ZHOU. Polk Community College, 999 Avenue H, N.E. Winter Haven, FL 33881. This session will cover some background information on Fibonacci Series as well as the presentation of a weekly challenge problem that can be related to a Fibonacci Series.

2:45 PM CMS-7 Fibonacci, Decomposed. LI ZHOU. Polk Community College, 999 Avenue H, N.E. Winter Haven, FL 33881. A solution and generalizations to Problem 10774 of The American Mathematical Monthly, January 2000 issue will be presented. The problem states: let F(1)=F(2)=1 and F(n)=F(n-1)+F(n-2) for n>2. Show that F(F(1998))^2+F(F(1999))^2=F(F(1997))*F(F(2000)).

3:00 PM CMS-8 Technology and the Learner: How not to do it Part I. MICHAEL O. MOORMAN Ph. D. Saint Leo University, Saint Leo, FL 33574. Technology in the classroom is one of the "hot" topics of current times. Teachers who do not use or aspire to use technology in their classes, however inappropriate, may be penalized. (Example: a class in philosophy may well not benefit from much use of high tech.) One of the major problems with using technology in the classroom is the lack of knowledge and skill of the user in the medium. There is nothing like having the bulb blow or the system crash or some other catastrophic problem occur when you have no backup. The objective of this presentation is to provide some of the major errors in the use of technology to illustrate the correct use of same.

3:15 PM CMS-9 Technology and the Learner: How not to do it Part II. MICHAEL O. MOORMAN Ph. D. Saint Leo University, Saint Leo, FL 33574. Technology in the classroom is one of the "hot" topics of current times. Teachers who do not use or aspire to use technology in their classes, however inappropriate, may be penalized. (Example: a class in philosophy may well not benefit from much use of high tech.) One of the major problems with using technology in the classroom is the lack of knowledge and skill of the user in the medium. There is nothing like having the bulb blow or the system crash or some other catastrophic problem occur when you have no backup. The objective of this presentation is to provide some of the major errors in the use of technology to illustrate the correct use of same.

3:30 PM BREAK

3:45 PM CMS-10 Non-Completion in Alternative Delivery Courses. BALBIR S. BAL, Ph.D. AND MICHAEL O. MOORMAN Ph. D. AND STEPHEN C. WINGREEN M.S. Saint Leo University, Saint Leo, FL 33574. The researchers compared the completion rates for students in two different delivery methods, traditional classroom vs. Internet (alternative delivery), for the same course in the same two semesters to determine if there was a difference in the completion rate between the different delivery methods. It was discovered that non-completion rates were higher for the Internet students and it was determined to perform further research to determine the cause of this. The researchers developed a questionnaire to be sent to non-completing students in the Internet program to inquire as to why they didn't complete the course. The results of the survey will be included in the presentation. This research should provide some valuable insights that can be used to improve program offerings and, hopefully, retain more students in these programs.

4:00 PM CMS-11 Use of the PC Printer Port for Experiment Control and the Collection of Data. ROBERT R. CRISS, Saint Leo University, Saint Leo 33574. The standard printer port on a personal computer can be used for bi-directional communication. With some effort, this allows it to be used in the laboratory for the control of experiments and the collection of data. In order to do so, the PC user must acquire skills in binary logic, digital electronics, and computer programming, but does not have to purchase new interface cards. In this paper we will provide a detailed example of printer port control/data collection and discuss some possible motivations for conducting experiments in this fashion.

4:15 PM BUSINESS MEETING: COMPUTER & MATHEMATICAL SCIENCES
JACCI WHITE, presiding

ENVIRONMENTAL AND CHEMICAL SCIENCES

FRIDAY 9:00 AM LEWIS 207
SESSION A
J. WILLIAM LOUDA, FLORIDA ATLANTIC UNIVERSITY, Presiding

9:00 AM ENV-1 Analysis of Toxicity of Lead Samples Using a MICROTOX 500 Analyzer. SHENGRONG CHEN AND DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, Tampa, FL 33620. The toxicity of environmental lead samples has been a matter of concern for many years. Typically, the total lead content is taken as a measure of the toxicity of a sample, whereas we might be better concerned with the speciation of the lead as well. For example, English soil samples that contained significant amounts of $Pb_5(PO_4)_3OH$ did not show bioconcentration in garden products. The present study describes the results of analysis of the toxicity of soluble lead solutions on the luminescent bacterium *Vibrio fischeri* and using the Microtox 500 as a means of assaying the toxicity of environmental samples.

9:15 AM ENV-2 Metal Ion Removal From Aqueous Media using Coordinating agents Supported on Silica Gel. CRAIG A. BOWE, ROBERT F. BENSON, AND DEAN F.MARTIN. Institute for Environmental Studies, Department of Chemistry, University of South Florida, Tampa, FL 33620. Silica gel was used as a support for amines and mercaptans to remove heavy metals from aqueous solutions. The current study reports results of an investigation involving the use of straight chain alkyl amines and mercaptans as coordinating agents in the removal of copper(II) and lead(II) from standard aqueous solutions . Amines used in the study range from the n-hexylamine through octadecylamine. Mercaptans used in this study are 1-octadecanethiol and 1-hexadecanethiol. The effect of coordination was evaluated as a function of pH for the copper and lead ions.

The mechanism by which the coordinating agents are affixed to silica gel takes place, is also currently under study, but two hypotheses are suggested: condensation for the amines and a corkscrew mechanism for the mercaptans.

9:30 AM ENV-3 Photolytic Decomposition of NO_2. KEVIN D. BELFIELD,* JOHN J. KARPF, and OZLEM YAVUZ. Department of Chemistry, University of Central Florida, P.O. Box 162366, Orlando, FL 32816-2366. Nitrogen dioxide (NO_2) is a common by-product of hydrocarbon fuel combustion in the atmosphere from combustion engines. The presence of toxic NO_2 is ominous and a major health and environmental concern, leading to respiratory problems in humans and animals, degradation of materials (building/structural materials, tires, etc.) and ozone depletion. Thus, there is great incentive to develop cost-effective NO_x reduction technologies. Among the promising remediation strategies are those based on photodecomposition. We report efforts directed towards laboratory photodecomposition of NO_x, simulating ambient conditions.

9:45 AM ENV-4 Microwave Activation of Hydrogen Peroxide for the Removal of NOX Species from Flue Gas Streams. L. PETTEY(1), P. MULLER(1), C. CLAUSEN(1), AND C. COOPER(2). Department of Chemistry (1) and Dept. of Civil and Environmental Engineering(2), University of Central Florida, Orlando, Fla.32816. NOX species are hazardous emissions from combustion sources. The EPA has created new regulations that require the removal of NOX species from industrial sources. Current technology is insufficient for many industrial applications due to cost of implementation. Pervious experiments showed that OH radicals from hydrogen peroxide could oxidize NOX to species that are easier to remove from the gas stream. This paper focuses on a novel technique for activating the hydrogen peroxide for NOX oxidation. Microwaves have been an ion source for mass spectroscopy for many years. The intense vibrations induced by microwaves causes high temperatures. At these temperatures, fragile bonds, like the peroxide bond, are likely to break producing radical species, as well as participate in reactions unfavorable at lower temperatures. Experiments showed that hydrogen peroxide in the presence of microwaves does in fact oxidize NOX species to some extent. The results of these experiments will be discussed, along with special experimental considerations for microwave experiments and proposed mechanisms of action. A pilot scale model will be introduced with preliminary results.

10:00 AM ENV-5 Removal of NOX Gases from Flue Gas Streams by the Use of Ultraviolet-Activated Peroxy Radicals. P. MULLER (1),

L. PETTEY (1), C. CLAUSEN (1), and C. COOPER(2) Department of Chemistry(1), Department of Civil and Environmental Engineering (2), University of Central Florida Orlando, FL. The EPA has responded to increasing environmental concerns of NOX pollution with implementing new emission standards. Current technologies to remove these gases are expensive and inefficient. Previous research has shown that NOX gases can be oxidized by peroxide radicals to acidic species that in turn can be effectively removed from the gas stream. Our research indicates that hydrogen peroxide exposed to ultraviolet radiation breaks the peroxide bond into free OH radicals. These radicals when properly introduced into the gas stream oxide NOX species. Currently, experiments focus on improving the applicability of the ultraviolet technology. External generation of the OH radicals before introducing them into the gas stream has been explored. Both liquid and gas phase peroxide injection were tested, as well as ultraviolet exposure and residence time. Results of these experiments and experimental setup will be discussed. Modifications from the lab scale to the pilot scale will also be presented, along with results from the pilot scale test.

10:15 AM BREAK and POSTER DISPLAY

SPECIAL SESSION

Biogeochemical Studies in Florida Bay, the Everglades, and their watersheds

Joint Session of the Atmospheric and Oceanographic Sciences Section
and the Environmental Chemistry and Chemical Sciences Section

William Louda (Florida Atlantic University)
and John Trefry (Florida Institute of Technology) presiding

10:30 AM J-1 Biogeochemistry of the Kissimmee-Okeechobee-Everglades-Florida Bay Hydroscape: Past, Present, and Future. LARRY BRAND. University of Miami, RSMAS, Miami, FL 33149. South Florida has a unique set of interlinked aquatic ecosystems. As a result, there is a high percentage of the total area under public protection. Ironically, these "protected" areas have undergone and continue to undergo major ecological changes. Many of the changes over the past century were the deliberate result of human actions(drainage, agriculture *etc.*). Additional changes are suspected of being the unintended and/or unexpected results of human actions. Efforts are now being made to reverse some of those changes. A major issue is whether or not these "restoration" efforts will also have unintended or unexpected results. An understanding of the biogeochemistry of these ecosystems in the past and present, and how they have and will change is critical to understanding the potential results of the ecological restoration projects currently being undertaken.

10:45 AM J-2 Is the Hg Problem in South Florida Expanding to the Lower Everglades and Adjacent Florida Bay? W.-J. KANG(1) AND J. H. TREFRY(2), Southwest Florida Water Management District, Brooksville 34609(1). Department of Marine & Environmental Systems, Florida Inst. of Tech., Melbourne 32901(2). Data for sediment and seagrass help define transport pathways as well as temporal and spatial patterns for inputs of excess Hg to the lower Everglades and Florida Bay. Inputs of excess Hg via runoff to post-1990 sediments near river mouths and adjacent Florida Bay were 2-6 times greater than the atmospheric flux of 24 ± 9 μg m^{-2} yr^{-1}. Thus, runoff is the primary means for carrying Hg to these areas. The distinctive spatial patterns for Hg in surface sediment and seagrass also support the importance of runoff loading of Hg versus direct atmospheric deposition. These results can help with development of water management strategies that prevent further expansion of Hg contamination.

11:00 AM J-3 Photosynthetic Pigment-Based Chemotaxonomy of Microalgal Communities in Lake Okeechobee and Florida Bay. J. WILLIAM LOUDA. Organic Geochemistry Group, Department of Chemistry and Biochemistry, Florida Atlantic University, Boca Raton, FL. 33431. Microalgal communities, phytoplankton and periphyton, including the microphytobenthos, are often complex assemblages which are difficult to taxonomically characterize by direct microscopy. Each photoautotrophic taxon has evolved with a characteristic complement of primary and accessory photosynthetic pigments (chlorophylls and carotenoids) plus a variety of 'sunscreen' pigments (carotenoids, scytonemin). This report covers 6 years of studies on the chemotaxonomic assessment of the phytoplanktonic, epiphytic and microphytobenthic communities in Lake Okeechobee and upper Florida Bay. Estimates are made by calculating taxon-specific chlorophyll-*a* based upon its ratio to taxon-specific biomarker accessory pigments (*e.g.* fucoxanthin/ diatoms, lutein/ chlorophytes, peridinin/ dinoflagellates, *et cetera*).

11:15 AM J-4 Flux of Inorganic Phosphate from the Sediment and Contribution to Biomass and Primary Productivity by Benthic Microalgal Communities in Western Florida Bay. GABRIEL A. VARGO AND MERRIE BETH NEELY, Univ. of South Florida, College of Marine Science, St. Petersburg 33701. The objective of this study is to address the relationship between benthic microalgal communities and the phosphate nutrient dynamics of Florida Bay sediments and how they relate to benthic and water column primary production. Inorganic phosphate (P) flux from the sediment was measured in chambers inserted into the sediment devoid of seagrasses under both light and dark conditions. Inorganic P flux measurements have been variable, but generally dark chambers show increasing P concentration while light chambers show a peak followed by a drop in P concentration. Chlorophyll values are variable both within and among samples but generally biomass is more than that in the water column. Dissolved oxygen measurements have been used as indicators of the benthic ecosystem net primary productivity.

11:30 AM J-5 Nutrient Ratios and Bioassays in Florida Bay. LARRY E. BRAND AND MAIKO SUZUKI FERRO, University of Miami, RSMAS, Miami, FL 33149. The inorganic N:total P ratio is higher than the Redfield ratio in eastern Florida Bay and lower in western Florida Bay, suggesting the potential for P limitation in the east and N limitation in the west. Nutrient bioassays of both phytoplankton and benthic microalgae show N limitation in the west and P limitation in the east, with a spatial distribution similar to the inorganic N:total P ratios. It is hypothesized that natural phosphorite deposits along the western side of Florida are the major source of the persistent P found in western Florida Bay and agricultural runoff through the Everglades is the major source of N in the east. The algal blooms in central Florida Bay, where natural P from the west meets anthropogenic N from the east, respond seasonally to freshwater runoff of N-rich water from the Everglades-agricultural watershed.

11:45 AM J-6 Policy Drought in South Florida: Will the Everglades Restoration Plan Further the Ecosystem Decline of Florida Bay and the Florida Reef Tract? B.E. LaPOINT (1) AND P.J. BARILE (2). Harbor Branch Oceanographic Inst. 5600 US1, Ft. Pierce, FL 34946(1), Environmental Science Program, Florida Tech, 150 W. University Blvd., Melbourne, FL 32901(2). Florida Bay has experienced unprecedented phytoplankton blooms, seagrass die-off, and cascading ecological dysfunction following water management policy to increase nitrogen-laden freshwater discharges from the Everglades watersheds south to Florida Bay. The Everglades Restoration Plan calling for increased discharges into Florida Bay is based upon an untested and unsupportable hypothesis that seagrass die-off events were the result of hypersaline conditions in the bay. Alternatively, we present evidence that Shark River slough discharges since 1991 were increased to 250% above the 20^{th} century average of 1 million acre-ft./yr. with corresponding increases in nitrogen loading. Our evidence points to future discharges associated with Everglades Restoration policy as a mechanism supporting eutrophication of Florida Bay and the Florida Reef Tract well into the new century.

FRIDAY 2:30 PM LEWIS 207
SESSION B
J. WILLIAM LOUDA, FLORIDA ATLANTIC UNIVERSITY, Presiding

2:30 PM ENV-6 Toxicity Studies on a MICROTOX 500 Analyzer on Organism-Organism Interaction of *Gymnodinium breve and Nannochloris sp..*, MELISSA DERBY(1), MICHAEL GALLIANO(1), DEAN F. MARTIN(1), AND JOSEPH J. KRZANOWSKI(2). Institute for Environmental Studies, Department of Chemistry(1); Department of Pharmacology and Therapeutics (2), University of South Florida, Tampa, FL 33620. In Florida, harmful algal blooms are caused by a red tide organism, known as *Gymnodinium breve, and* occur every 3-5 years usually in the autumn following periods of heavy rainfall. Outbreaks will cause high mortality rates among fish, dolphins, manatees, and other wildlife. In humans, the side effects that occur are respiratory problems-- lacrimation, rhinorrhea, and asthma-like symptoms to name a few. What causes these problems to occur when a red tide outbreak happens? The red tide releases toxins, known as brevetoxins that cause these problems. Each brevetoxin has a different effect. Researchers are looking into controlling the red tide outbreaks so that these problems do not occur. In 1975, Kutt and Martin discovered a blue-green alga found naturally in the marine environment released allelochemicals later termed APONINs (Apparent Oceanic Naturally occurring CytolINs). At least four algal species produce these APONINs, and the present study is concerned with properties of APONIN-1 from the algal strain *Nannochloris sp.* APONIN-1 was tested against a known concentration of *Gymnodinium breve* in enriched seawater medium and was cytolytic. The mixed cultures to be assayed were tested for toxicity using the Microtox 500 analyzer. Preliminary results showed that brevetoxins were not released in detectable amounts when *G. breve* was exposed to APONIN-1 or when the cultures of *Nannochloris sp* and *G. breve* interacted.

2:45 PM ENV-7 Toxicity Studies done on a MICROTOX 500 Analyzer on the Release of Brevetoxins from the Organism *Gymnodinium breve..* MELISSA DERBY(1), MICHAEL GALLIANO(1), DEAN F. MARTIN(1),[1] AND JOSEPH J. KRZANOWSKI(2). Institute for Environmental Studies, Department of Chemistry(1); Department of Pharmacology and Therapeutics(2), University of South Florida, Tampa, FL 33620. Since the 1970s there has been a rise in the number of harmful algal blooms that occur in the United States (Harvell et al., 1999). The harmful algal bloom in Florida, known as *Gymnodinium breve* (red tide), occurs every 3-5 years unless conditions for an outbreak are good. Researchers at the Institute for Environmental Studies have been studying how to mitigate the red tide using a concept of allelopathy (the control of one organism by another). Three algal strains of *Nannochloris spp.* that can lyse *G. breve* cells through the production of lysins, termed APONINS (APparent Oceanic Naturally occurring cytolINs). These strains are being looked at closely and allelochemicals are being identified. In this study, however, we examining the conditions under which the toxins produced by the Florida red tide, known as brevetoxins, are released into the environment. Earlier studies indicated that in cultures of *G. breve* the toxins were not released, but when centrifuged a small amount of the toxin was released. This study confirmed that the toxin was not released when the red tide was undisturbed, however, when red tide culture was stressed (stirred at high on the stirrer plate continuously for 24, 48, and 72 hours) the toxin was released and the toxicity could be measured using the Microtox analyzer. This instrument measures the effect of toxic substances on a luminescent bacterium, *Vibrio fischeri*.

3:00 PM ENV-8 Characterizing the Naturally Occurring Substances That Inhibit the Growth of *Hydrilla verticillata*. DAVRON L. DAVIS AND DEAN F. MARTIN, Institute for Environmental Studies, Department of Chemistry, University of South Florida, Tampa, FL 33620. *Hydrilla verticillata* a submersed aquatic plant was introduced into Florida about 1959. Subsequently it has spread to number of areas of the United States. It is a serious problem in waterways or lakes, because of its ability to form dense mats and occupy the top meter of water thus shading out and dominating the macrophytic communities. Previous studies have shown that several lakes do not support hydrilla as well as others. Dooris and Martin (1980) suggested that the inhibition may be a result of microbial digestion of cellulose. Metabolic products from the microbial digestion of cellobiose have shown inhibitory effects towards hydrilla in the laboratory. The current study involves characterizing the metabolic products produced by the digestion of cellobiose.

3:15 PM ENV-9 Surface modification and coating of silicon wafers. KEVIN D. BELFIELD*, GOMAA G. ABDEL-SADEK. Department of Chemistry, University of Central Florida, P.O. Box 162366, Orlando, FL 32816-2366. Coatings of silicon wafers with polymeric materials poses a significant challenge due to the vastly different surface energies of the two materials. The surface of silicon wafers was activated by annealing at different temperatures, such that, at higher temperatures (1000 °C) a good adhesion strength between the silicon substrate and polymer film was observed. Furthermore, chemical treatment of the silicon surface with Hypalon (chlorosulfonatedpolyethylene), 3-aminopropyltriethoxysilane (APTES), 3-chloropropyltrimethoxysilane (ClPTMS), and 3-glycidoxypropyltrimethoxysilane (GPTMS), acts as an adhesion promoter, improving the adhesion strength of polymer sheets to the silicon surface. Variations in treatment conditions such as temperature, time of baking, surface activation, and the type of organic surface modifier used had significant effects on the adhesion results.

3:30 PM BREAK and POSTER DISPLAY

3:45 PM ENV-10 Modeling Reactions in Proteins Using Stretched Exponentials. HARRY L. PRICE, Dept. of Chemistry, University of Central Florida, Orlando, 32816-2366. Dynamic motions of a protein allow a reacting group to transiently occupy a volume of space that can also be occupied by a second reactant The notion that protein surfaces display a distribution of accessibilities supported on a flexible geometric scaffold (the protein backbone) as provided an alternative way (fractal models) to interpret how the structure and dynamics of a protein influence processes occurring on or within its interior. The main goal of this work was to demonstrate that reactions classically described as nonexponential and modeled using a sum exponentials, can be described using a fractal model based on a sum of stretched exponentials, $f(t) = \Sigma \mathrm{A_i}\mathrm{exp}(-k_i\mathrm{t})^{\alpha i}$. The scaling term α, provides a description of the fractal character of the reaction volume associated with a particular class of reaction site.

4:00 PM ENV-11 Mercury Analysis of the Waters of a College Campus. DANNY LANDAU (1), JEROME E. HAKY (1) AND YASMIN VAELI (2). (1) Florida Atlantic University, Boca Raton 33431, (2) Banian Technologies, 1761 W. Hillsboro Blvd. Deerfield Beach, 33442. Using the highly sensitive technique of atomic fluorescence spectroscopy, water samples from several sources on the campus of Florida Atlantic University were analyzed for mercury content. Samples included tap water from several different campus buildings, water obtained from canals and ponds on the campus and water extracted from sinks located in both laboratory and non-laboratory buildings. Small but measurable quantities of mercury were found in several of these samples, mostly at part per trillion levels. Surprisingly, the highest concentration of mercury was found in samples of tap water from Physical Sciences, the newest building on campus.

4:15 PM ENV-12 Chlorophyll and Carotenoid Breakdown During the Senescence and Death of Various Marine Phytoplankton. J. WILLIAM LOUDA, LEI LIU AND EARL W. BAKER. Organic Geochemistry Group, Department of Chemistry and Biochemistry, Florida Atlantic University, Boca Raton, FL. 33431. Ongoing studies in our laboratory are aimed understanding the overall biogeochemistry of the photosynthetic pigments, the chlorophylls and carotenoids. The geochemistry of these pigments involves their *fossilization* which, in the cases of the chlorophyll nuclei, can be for periods of up to 200 My or more. The beginning of organic diagenesis starts with the senescence-death induced changes in these pigments and has much to do with their subsequent fate (remineralization *vs.* fossilization). We report here a several years study on the changes induced by incubating 5 species of marine phytoplankton in the dark at room (24^0C) or refrigerator (2-4^0C) temperatures and with or without free oxygen exchange. Several pertinent reactions were able to be followed and include: the deacetylation of fucoxanthin to fucoxanthinol, the loss of Mg from chlorophyll-*a* to produce pheophytin-*a*, the novel reduction of the triple bond in diatoxanthin to give 7-*cis*-zeaxanthin, and several others.

4:30 ENV-13 Stereochemistry of Compounds of the Type $[\{RCOCH'C(NR')R''\}_2Ni]$. BRIAN MOULTON, MICHAEL J. ZAWOROTKO, AND DEAN F. MARTIN. Department of Chemistry, University of South Florida, Tampa, FL 33620. Compounds of the referenced type have been described previously [Florida Scient.55:22-27]. The stereochemistry could be planar, distorted tetrahedron, or octahedral (through association). Molecular weight determinations seemed to eliminate the last possibility, and partial resolution over D-lactose seemed to favor a distorted tetrahedron [Inorg. Chem. 2: 587-590]. We are currently obtaining structures by means of x-ray crystallography, which will provide the definitive answer concerning the general stereoisomerism as well as a case of apparent isomerism ($R=R' = C_6H_5$; $R'' = CH_3$).

4:45 PM ENV-14 Residual Chlordane Found in Soil as a Function of Depth at Homes along the Central St. Johns River Basin. L. FILIPEK AND C. L. GEIGER. University of Central Florida Departments of Chemistry, Orlando Florida, 32816-2366. Many homes along the Central St. Johns River basin are homes that were built prior to chlordane being banned from use. Because of its common use as a preventative chemical for termite infestation prior to that time (1988), chlordane was used on most homes built before that date. Chlordane has a long half-life and easily identifiable degradation by-products. Since these homes are located in areas where the groundwater level is relatively high and flow is in the direction of the St. Johns River, a study is currently being conducted to determine the effects of groundwater flow and surface runoff on the transport of chlordane and its degradation by-products. Results of this study will be presented.

SATURDAY 9:00 AM LEWIS 207
SESSION C
J. WILLIAM LOUDA, FLORIDA ATLANTIC UNIVERSITY, Presiding

9:00 AM ENV-15 Synthesis and photophysical properties of fluorine derivatives for two-photon absorbing dyes. KEVIN D. BELFIELD*, BONG-SOO KANG, OZLEM YAVUZ. Department of Chemistry and School of Optics, University of Central Florida, P.O. Box 162366, Orlando, FL 32816. Two-photon absorption has a number of inherent characteristics that make it attractive for use in a number of fast emerging technologies, foremost among them is multiphoton fluorescence imaging. A series of fluorene derivatives with 2-(4-vinylphenyl)benzothiazole and/or diphenyl-(4-vinylphenyl)amine were synthesized by efficient Pd-catalyzed Heck type coupling reactions. These derivatives were characterized, including linear absorption, quantum yield, single photon fluorescence, and two-photon upconverted fluorescence. The UV-visible absorption spectra of these derivatives show appropriate absorption in the range of interest suitable for two-photon excitation by near-IR femtosecond lasers. These derivatives exhibit high two-photon absorptivity and exhibit two-photon upconverted fluorescence.

9:15 AM ENV-16 Fluorene derivative for multiphoton absoption. KEVIN D. BELFIELD*, EMILIO J. MANGUAL , ALMA R. MORALES, OZLEM YAVUZ. Department of Chemistry, University of Central Florida, P.O. Box 162366, Orlando, FL 32816. A series of new intermediate fluorene derivatives were prepared for multiphoton absorption. Through variation of iodofluorene, derivatives such as 9,9-didecyl-2,7-diiodofluorene (1) and 7-iodo-9,9-didecyl-2-nitrofluorene (2) were used to synthesize key intermediates in good yield. 2,7-dicyano-9,9-didecylfluorene (3) and 7-iodo-9,9-didecyl-2-cyanofluorene (4) were synthesized through nucleophillic substitution with CuCN. Quantitative reduction of (4) with hydrazine over graphite produced 2-amino-7-cyano-9,9-didecylfluorene (5). Ullmann amination reactions were employed to provide 2-(9,9-didecyl-7-cyanofluorene-2yl)diphenylamine (6) and 9,9-didecyl-2,7-diphenylaminofluorene (7). 2-Benzothiazole-7-cyano-9,9-didecylfluorene (8) was synthesized by condensation of (3) and 2-aminobenzenethiol with PPA. All of the fluorine derivatives were fully characterized including excitation and emission spectra.

9:30 AM ENV-17 Electrochemical Studies of Fluorene Containing Dyes. KEVIN D. BELFIELD*, OZLEM YAVUZ, KATHERINE J. SCHAFER, ALMA MORALES and BONG-SOO KANG. Department of Chemistry, University of Central Florida, P.O. Box 162366, Orlando, FL decades about organic π-electron conjugated monomers and their polymers as a class of nonlinear optical (NLO) materials, as they have high mechanical, thermal and environmental stabilities and are important components of polymeric waveguides and light emitting diodes. In this respect, diphenylamine and benzothiazole containing monomers and their polymers were synthesized by our group. We previously reported structural and photophysical characterization of these materials. Here, cyclic voltammetry (CV), a technique to obtain oxidation and reduction potentials of the materials was employed for the electrochemical characterization of a number of fluorene compounds. *In-situ* spectroelectrochemical studies were performed in order to get information about reaction pathways, since oligomeric species were observed forming in solution during the CV measurements.

9:45 AM ENV-18 A New Class of Bisbenzothiazole Polymer. KEVIN D. BELFIELD*(1), ALMA MORALES (1,2) OZLEM YAVUZ (1), GEORGE I. STEGEMAN (1) VICTOR M. CHAPELA (2) and JUDITH PERCINO(2). Department of Chemistry and School of Optics, University of Central Florida, P.O. Box 162366, Orlando, FL 32816 (1). Centro de Quimica, Benemerita Universidad Autonoma de Puebla, Puebla, Mexico (2). Simultaneous multiphoton absorption is a process in which the probability of a ground to excited state transition scales nonlinearly with incident intensity of the irradiation source. Multiphoton absorption has a number of inherent characteristics that make it attractive for use in a number of fast emerging technologies, including multiphoton fluorescence imaging, microfabrication, and optical power limiting to name but a few. To meet the needs of these, and other, applications, the design and synthesis of polymeric materials that exhibit high multi- or two-photon absorption is critical. Herein, we describe the synthesis, structural characterization, and photophysical characterization of a fluorenyl bisbenzothiazole-based polymer produced via polycondensation of a dicyano monomer with 2,5-diamino-1,4-benzenedithiol. Photophysical properties including linear absorption, excited state lifetime, quantum yield, single photon fluorescence, and two-photon upconverted fluorescence emission spectra are reported.

10:00 AM ENV-19 New agents for two-photon photodynamic cancer therapy. KEVIN D. BELFIELD*, BRIAN POLK, KATHERINE J. SCHAFER, JOHN BIGGERSTAFF. Department of Chemistry, University of Central Florida, P.O. Box 162366, Orlando, FL 32816. The possibility of using two-photon absorbing compounds to treat cancer is very attractive for a number of reasons. These reasons include the preferred use of a non-damaging, near IR light source, reduced light scattering, and better depth penetration with possible three-dimensional resolution. The work discussed herein has been designed to address the problems that have limited the success of previous work in this field. First, a drug that could serve as a model for possible water-soluble dyes was synthesized and characterized. This fluorenyl derivative may possibly be modified to impart water solubility, thus allowing it to be easily taken up into the cell. Next, several organic compounds were encapsulated in liposomes and introduced to tumor cells. The strategy for encapsulating and evaluating the biological activity of these compounds was three fold. First we had to confirm encapsulation with fluorescence microscopy. The next step was to verify cellular uptake and insure that the encapsulated drug did not have significant toxicity without irradiation. Finally, we needed to verify photodynamic therapeutic activity.

10:15 AM BREAK AND BUSINESS MEETING
ENVIRONMENTAL CHEMISTRY AND CHEMICAL SCIENCES
J. WILLIAM LOUDA, presiding.

10:45 AM ENV-20 Emulsified Zero-Valent Nanoscale and Microscale Iron Particles for Use in Remediation of DNAPLs. R. DeVOR, C. L. GEIGER, C. A. CLAUSEN, K. B. BROOKS. Chemistry Department, University of Central Florida, Orlando, Florida, 32816-2366. Groundwater contaminated with chlorinated solvents is found at over 70% of the Superfund sites throughout the U.S. Many remediation technologies have been attempted for aqueous-phase contamination but the source contamination, where dense non-aqueous phase liquids are found in pools or smeared within the soil matrix, present a very difficult remediation problem. Studies will be presented that show results of kinetic experiments conducted on several candidate emulsions and comparisons of their commercial viability.

11:00 AM ENV-21 Field Study on the Effectiveness of Ultrasound Application for Permeable Treatment Walls. C. L. GEIGER, C. A. CLAUSEN, D. R. REINHART, A. SANOWONE, and C. CLAUSEN. University of Central Florida Departments of Chemistry and Civil and Environmental Engineering, Orlando Florida, 32816-2366. Permeable treatment walls have gained popularity in the past decade as a passive remediation technology for the treatment of groundwater contaminated with chlorinated solvents. Commonly, an active metal, usually iron, is used as an electron donor for reductive dehalogenation reactions with the chlorinated solvent. Since iron goes through a corrosion reaction during this remediation process, precipitates form on the iron surface thus leaving the permeable treatment wall less reactive and can even alter groundwater flow around the wall. After several years of laboratory study, ultrasound was used on three different PTWs. Results will be presented showing the successful treatment of these field installations.

11:15 AM ENV-22 Laboratory Experiment Using an Iron/Surfactant/Oil Emulsion to Degrade DNAPL Pools. T. BERRIOS, C. L. GEIGER, C. A. CLAUSEN, K. BROOKS, C. M. CLAUSEN. Chemistry Department, University of Central Florida, Orlando, FL 32816-2366. Many remediation methodologies are currently being studied for the treatment of groundwater contaminated with chlorinated solvents (aqueous phase contamination). However, there have been no useful technologies found for treating the source of this contamination, the dense, non-aqueous phase liquids (DNAPL) found in the subsurface as pools of chlorinated solvents or chlorinated solvents smeared within the soil structure. Researchers at UCF have developed a novel approach of using a hydrophobic emulsion containing iron, oil, and surfactant to sorb and degrade trichloroethylene in-situ. Results of laboratory studies will be presented that show the process for selecting the most appropriate and effective emulsion.

11:30 AM ENV-23 Two-photon cationic polymerization using near-IR light. KEVIN D. BELFIELD*, JUN LIU. Department of Chemistry, University of Central Florida, P.O. Box 162366, Orlando, FL 32816. The quest for organic materials exhibiting high nonlinear optical (NLO) absorptivities has increased dramatically over the past several years. Two-photon absorption (TPA), a nonlinear absorption process, is the subject of intense interest in the chemistry, photonics, and biological imaging communities. Several current and emerging technologies exploit the TPA phenomenon, including multiphoton fluorescence imaging, optical power limiting materials, two-photon photodynamic cancer therapy and two-photon microfabrication. Emerging device technology such as microelectromechnical system and integrated sensors are placing increased demands on the development of materials processing and fabrication techniques. In response, the characteristic three – dimensional spatial resolution of the simultaneous two–photon absorption (TPA) process is being harnessed for 3 – D photo initiated polymerization, facilitated by the nonlinear properties associated with simultaneous absorption of two photons. We wish to report our efforts in near-IR two-photon induced cationic polymerization of epoxide and vinyl ether monomers using commercially available photo initiator systems. Details of the laser system, polymerization experiments, characterization, and resulting microstructures will be presented.

11:45 AM ENV-24 Modification of polymers with two-photon absorbing fluorophores. KEVIN D. BELFIELD,*(1,2) STEPHEN ANDRASIK (1), KATHERINE J. SCHAFER (1,2), OZLEM YAVUZ (1) JOEL M. HALES (2) and ERIC W. VAN STRYLAND (2). Department of Chemistry (1) and School of Optics (2), University of Central Florida, P.O. Box 162366, Orlando, FL 32816. Simultaneous two-photon absorption is a process in which the probability of a ground to excited state transition scales quadratically with incident intensity of the irradiation source. This nonlinear or quadratic dependence makes two-photon excitation particularly attractive for use in a number of emerging technologies, including two-photon fluorescence imaging, three-dimensional microfabrication, and optical power limiting. We wish to report the synthesis and photophysical characterization of polymers bearing chromophores that exhibit high two-photon absorptivity. Polymers derived from copolymerization with maleic anhydride or through grafting of maleic anhydride were modified with primary amine-containing two-photon fluorophores, affording the corresponding imides. Photophysical properties including, linear absorption, excited state lifetime, single photon fluorescence, and two-photon upconverted fluorescence emission spectra are reported.

12:00 PM ENV-25 Two-photon fluorescence imaging of polymeric materials. KEVIN D. BELFIELD,* (1,2) KATHERINE J. SCHAFER (1,2) and ERIC W. VAN STRYLAND (2). Department of Chemistry (1) and School of Optics/CREOL (2), University of Central Florida, P.O. Box 162366, Orlando, FL 32816. Simultaneous multiphoton absorption is a process in which the probability of a ground to excited state transition scales nonlinearly with incident intensity of the irradiation source. Multiphoton absorption has a number of inherent characteristics that make it attractive for use in a number of fast emerging technologies, foremost among them is multiphoton fluorescence imaging. Nondestructive imaging of polymer coatings and composites is potentially important in a wide range of applications for failure detection, quality inspection, and morphological investigations. To meet the needs of these, and other, applications, we wish to report the design of efficient multiphoton absorbing chromophores, their photophysical properties, and their application in three-dimensional, nondestructive multiphoton fluorescence imaging of a number of polymeric materials, from fibrin to conventional synthetic polymers.

FAS POSTER SESSION (ENV)
FRIDAY, 9:00 AM – 5:00 PM
LEWIS FIRST FLOOR HALLWAY

POS-1 Hemolytic Assays of *Nannochloris sp.*, A Potential Red-Tide Control Agent. MICHAEL GALLIANO(1), MELISSA DERBY(1), DEAN F. MARTIN(1), AND JOSEPH J. KRZANOWSKI(2). Institute for Environmental Studies, Department of Chemistry(1), Department of Pharmacology and Therapeutics(2), University of South Florida, Tampa, FL 33620.

POS-2: Quasi-stabilization of recent carbonate marl sediments in Florida Bay by weak hydrogel formation. J. WILLIAM LOUDA (1), WILLIAM H. OREM (2), ATHANSIOS MELISIOTIS (1), JOSEPH W. LOITZ (1,3) and EARL W. BAKER (1). Organic Geochemistry Group, Florida Atlantic University, Boca Raton, FL. 33431 (1). United States Geologic Survey, Reston, VA.20192 (2). South Florida Water Management District, Skees Road Laboratory, West Palm Beach, FL. 33416.

FLORIDA COMMITTEE ON RARE AND ENDANGERED PLANTS AND ANIMALS

FRIDAY 9:00 AM LEWIS 120
DEAN BAGLEY, UNIVERSITY OF CENTRAL FLORIDA, presiding

9:00 AM REB-1 Florida Endangered Epiphytic Bromeliads and Their Inhabitant Arthropod Macrofaunas. M. M. OLSON, New College of University of South Florida, 5700 North Tamiami Trail, Sarasota 34243. Arthropod assemblages inhabiting epiphytic tank *bromeliads (Tillandsia utriculata*, *Tillandsia fasciculata*, and *Guzmania monostachia*) in Myakka River State Park and Fakahatchee Strand State Preserve were collected and identified. Abundance, diversity, and population density measures are compared between the bromeliad species, between intraspecific size classes, and between the two Florida study areas. Additional data collected from Isla Colón, Panama, provides a comparison of subtropical and tropical bromeliad arthropod assemblages. The evolution and ecological significance of phytotelm bromeliads is discussed, and the future of the endangered species is addressed with emphasis placed upon the spread of the phytophagous weevil *Metamasius callizona*.

9:15 AM REB-2 Site History and Assessment of suitable habitat for growth of *Jacquemontia reclinata*. LESLEY A. VINCENT, Palm Beach Atlantic College, 901 S. Flagler Dr., P.O. Box 24708, West Palm Beach, FL 33407. *Jacquemontia reclinata* is an endangered plant endemic to the southern coast of Florida. It was classified in 1993 with less than 1,000 individual plants in 12 sites but is now thought to only exist in seven locations with a little more than 600 remaining. The decline in populations has been a result of human interference, development and beach erosion. The U.S. Fish and Wildlife Service have noted that *J. reclinata* has been historically maintained by hurricanes and possibly fires by clearing ground space, but they now pose a threat due to the sparse populations. Another major hurricane is expected to approach south Florida by the year 2003 which makes it vital to determine a suitable habitat as well as develop stable populations. *J. reclinata* has been successfully propagated from seed for the last five years by Fairchild Tropical Garden and the Center for Plant Conservation. With the hopes of transporting these plants to their natural habitat, only 10 self-sustaining populations could downgrade *J. reclinata* from endangered to threatened.

9:30 AM REB-3 Preliminary estimates of eastern indigo snake home range sizes, cause-specific mortality, and survival. M. L. LEGARE, R. B. SMITH AND D. R. BREININGER, The Dynamac Corporation, Mail Code DYN-1, Kennedy Space Center 32899. The eastern indigo snake, *Drymarchon corais couperi*, has been federally listed as a threatened species since 1978. However, much of the information needed to conserve and manage for indigo snake populations does not exist, such as home range sizes, cause-specific mortality, and survival. Since January 1998, we have captured, measured, radiotagged, and released 72 eastern indigo snakes in a variety of habitats throughout Brevard County, Florida. Minimum convex polygon home range sizes, based on weekly telemetry locations, range between 70-150 ha for females and 75-300 ha for males. Known mortality events have occurred from a variety of sources including road kills, intentional human destruction, and pre-existing illnesses. We developed survival estimates for both males and females. Preliminary analyses on the impacts of habitat fragmentation on adult indigo snake survival are presented.

9:45 AM REB-4 Satellite Tracking Leatherbacks from the Archie Carr National Wildlife Refuge on the East Coast of Florida. D. A. BAGLEY (1), S. A. ECKERT (2) AND L. M. EHRHART (1), (1) Dept. of Biology, University of Central Florida, Orlando 32816-2368, (2) Hubbs SeaWorld Research Institute, 2595 Ingraham St., San Diego, CA 92109. With zero to four nests per season from 1982 until 1995, south Brevard

County was not regarded as an important leatherback nesting beach. From 1996 through 2000 however, leatherback nesting increased markedly in that area. The 1999 season culminated in a total of 25 nests in the Archie Carr National Wildlife Refuge. A project designed to study this phenomenon more closely during the 2000 season resulted in a special collaboration and the attachment of a satellite transmitter to one of the nesting females. In 1994 this turtle became the second leatherback ever tagged by the UCF group and was the first to be recaptured in subsequent years while nesting in the Carr Refuge. Upon deployment on 19 May, 2000, she became the first leatherback to be tracked from a U.S. nesting beach. Named "China girl", she has traveled more than 7,000 km, while remaining within 100 km of the U.S. Atlantic coastline. These results may begin to change our perceptions of a species considered to be thoroughly pelagic.

10:00 AM BREAK

10:15 AM REB-5 Nesting Frequency and Hatching Success of the Leatherback Turtle (*Dermochelys coriacea)* in Central and South Brevard County, Florida. A. M. MAHARAJ AND L. M. EHRHART, Dept. of Biology, University of Central Florida, Orlando 32816-2368. Prior to 1983, there was no recorded leatherback (*Dermochelys coriacea*) nesting in Central and South Brevard County, Florida. Since then numbers have increased, reaching as many as 30 nests in one season. We examined the nesting frequency of leatherback turtles from 1982-2000. We compared hatching success for green turtles (*Chelonia mydas*) and loggerheads (*Caretta caretta*) to that of the leatherbacks for the years 1993 to 2000 in our study site. We also compared leatherback hatching success in Brevard County, Florida to that at other Atlantic nesting beaches. Hatching success remained relatively constant at an average of 33% hatched. This is comparatively low with regard to loggerhead and green turtles on our study site. Hatching success at other Atlantic sites showed higher hatching success rates than at our study site for the same years. This comparison showed that Central and South Brevard County, Florida has a lower leatherback hatching success rate than the two other species in the area as well as leatherbacks in other Atlantic nesting colonies.

10:30 AM REB-6 Demographic data on the Southeastern beach mouse (*Peromyscus polionotus niveiventris*) on Cape Canaveral Air Force Station. D. M. ODDY (1), AND I. J. STOUT (2), Dynamac Corporation, Mail Code DYN-2, Kennedy Space Center 32899, (2 Dept. of Biology, University of Central Florida, Orlando 32816-2368. Demography data were collected on the southeastern beach mouse (*Peromyscus polionotus niveiventris*) on Cape Canaveral Air Force Station (CCAFS). Baseline data were collected on this subspecies on CCAFS in the late 1970's. This two-year study provided current data on seasonal abundance, body weights, age structure, sex ratios, reproductive activity and recapture information on four grids located on CCAFS. Six hundred and thirty-nine individual beach mice were recaptured on 1,069 occasions. Fall 1995 yielded the lowest numbers on all grids associated with post-hurricane/tropical storm conditions. Highest numbers of individual beach mice were captured in the Fall season on each of the grids followed by Winter, except at grid LC17, where Summer was second highest. Sex ratios were close to unity on grids LC2529 and LC17 but showed more deviation at grids AQ and JETTY, significantly so at grid JETTY. Adults dominated the captures on the grids, followed by subadults and juveniles. No juveniles were captured in Fall 1995 most likely as a result of the hurricane/tropical storm conditions causing their direct mortality. Eighty-four percent of the juvenile captures occurred in the Fall and Winter with just 4.8% in the Spring. Reproductively active males and females were observed in all seasons on the grids but were most prevalent in Fall. Numbers of recaptures were greater than new captures during most trapping periods and frequencies of individual recaptures were higher for females than males on each of the four grids. The majority of mice were captured 1-2 times, which may reflect mortality between seasonal sampling events.

10:45 AM REB-7 Population Status of Beach Mice, *Peromyscus polionotus niveiventris*, in the southernmost portion of Canaveral National Seashore, Florida. MARIO MOTA (1), JOLENE WEIDLICH (2) AND JOHN STINER (3), (1) NASA/ Dynamac Corp. DYN-1, KSC 32899, (2) NASA/ Dynamac Corp. DYN-2, KSC 32899, (3) Canaveral National Seashore, 308 Julia St., Titusville 32796. The southern Canaveral National Seashore (CNS), known as Playalinda Beach, abuts the border of Kennedy Space Center (KSC), and is an ideal habitat for beach Mice *(Peromyscus polionotus niveiventris*). KSC Ecologists confirmed a large population of this species near the Space Shuttle Launch Pads, and in the early 1990s a low number of individuals were confirmed in the National Park. This low number was believed to be partially due to public disturbance. However, in 1993 the southern portion of Playalinda Beach was closed to the general public. Because the decreased disturbance ameliorated habitat suitability, this study investigates the present *P.p. niveiventris* population. Four study areas were chosen; two in the northernmost end of KSC, and two in the southern-most portion of CNS. Each study area included two transect lines with Sherman live-traps baited with sunflower seeds. Trapping was conducted during three consecutive nights in the spring starting one day before the new moon phase. Results show that *P.p. niveiventris* is present in all sites, although the KSC sites had a higher density of animals. This confirmed that the existing KSC beach mice population is active, and that its range has extended to CNS. It appears that the seven years of relatively low disturbance allowed the population of Florida beach mice to reestablish itself back on CNS.

11:00 AM REB-8 Habitat use by the Southeastern big-eared bat, *Corynorhinus rafinesquii macrotis,* in the Lower Reedy Creek Swamp . L.S. FINN. Fly By Night, Inc., 431 Sheryl Dr. Deltona, FL 32738. During four two-week sessions in 1999 and early 2000 19 *Corynorhinus rafinesquii* were radio-tracked near the Disney Wilderness Preserve and Lower Reedy Creek swamp. The objectives of the project were to identify alternate roosts and preferred foraging areas and to determine how (if) the roosting and foraging behavior was affected by airboat traffic on Reedy Creek. Data and results on alternate roosts will be presented. Eighteen roosts in three tree species were identified. As a result of seasonal variation, the small number of bats tracked each session, and the small number of bats roosting in each tree the sample size was too small to make substantive conclusions. However, day roosting by transmittered bats did not appear to be significantly affected by airboat activity.

11:15 AM BUSINESS MEETING
LAURA FINN, FLY BY NIGHT, INC., presiding

FAS POSTER SESSION (REB)
FRIDAY 9:00 AM – 12:00 PM
LEWIS FIRST FLOOR HALLWAY

POS-1 Extraordinary Capture Rates of Juvenile Green Turtles Over a Near Shore Reef at Sebastian, FL in the Summer of 1999. K. G. HOLLOWAY-ADKINS, S. A. KUBIS, A. M. MAHARAJ, AND L. M. EHRHART, Dept. of Biology, University of Central Florida, Orlando 32816-2368.

POS-2 Marine Turtle Nesting At The Archie Carr National Wildlife Refuge: The 2000 Season And Long Term Trend. D. A. BAGLEY, S. A. KUBIS AND L. M. EHRHART, Dept. of Biology, University of Central Florida, Orlando 32816-2368.

POS-3 Spatiotemporal Distribution of Marine Turtle Nests in South Brevard County and the Archie Carr National Wildlife Refuge 1989-1999. UCF MARINE TURTLE RESEARCH GROUP AND LANDSCAPE ECOLOGY CLASS. Dept. of Biology, University of Central Florida, Orlando 32816-2368.

GEOLOGICAL AND HYDROLOGICAL SCIENCES

FRIDAY 7:55 AM LEWIS 206
SESSION A
RICK COPELAND, FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION, presiding

SPRINGS SYMPOSIUM

UNDERSTANDING KARST IS KEY TO PROTECTING FLORIDA'S SPRINGS

7:55 AM Introduction – RICK COPELAND

THREATS TO SPRINGS IN BOTH FLOW AND WATER QUALITY, AND PROTECTIVE MEASURES TO BE TAKEN

8:00 AM GHY-1 Florida Springs: Past, Present and Future. J. A. STEVENSON, Florida Department of Environmental Protection, Division of State Lands, 3900 Commonwealth Blvd. MS140, Tallahassee, 32399. According to legend, Florida was discovered by Ponce de Leon during his search for a spring. Since then 600 springs have been discovered and enjoyed by residents and tourists. Health spas were built at a number of springs in the early 1900's because of their perceived medicinal qualities and churches commonly conducted baptisms in local springs. Florida's 33 first magnitude springs exceed in number and quantity of water discharged those of any country. Today increasing levels of contamination and loss of discharge are seriously degrading the natural, recreational and economic values of many of the springs. The Department of Environmental Protection formed the Florida Springs Task Force to develop protection strategies for Florida's Springs and introduced the Florida Springs Initiative in the 2001 Legislative session. Implementation of the twelve strategies is underway.

8:15 AM GHY-2 Water Quality Trends in Floridan Springs of the St. Johns River Water Management District. W. L. OSBURN, St. Johns River Water Management District, P.O. Box 1492, Palatka FL 32178. The St. Johns River Water Management District has 70 known springs or seeps, of which 61 are believed to have water sources originating in the Floridan Aquifer System. To date 20 of these springs have sufficient water quality data to perform trend analyses. Trend analyses utilizing Sen's Slope and Seasonal Kendal non-parametric statistical tests were performed on chloride

(Cl), sulfate (SO4), and total nitrite plus nitrate (NO3). Total NO3 is considered to be an anthropogenic indicator. Chloride and SO4 could be either anthropogenic or non-anthropogenic indicators. Data suggests that Cl may be considered to be an anthropogenic indictor when the median Cl concentration less than 30 mg/L, while above 100 mg/L it may be a non-anthropogenic indicator. Chloride is increasing at eight springs, and decreasing at one. The Cl trends at six springs are believed to be the result of non-anthropogenic factors. For these six springs there may have been a change in the ratio of shallow to deeper Floridian aquifer waters contributing to spring discharge. This change could be due to changes in rainfall or ground water withdrawals, or a combination of both. The increasing Cl trends at three springs are believed to be the result of anthropogenic factors. There is no clear break for SO4. A tentative break point may be around 50 mg/L. Below 50mg/L SO4 the trends may be anthropogenic, above 50 mg/L non-anthropogenic. Sulfate is increasing at five springs and decreasing at two. The SO4 trends at five springs are believed to be the result of non-anthropogenic factors. The same forces responsible for the chloride trends may be causing the SO4 trends at these five springs. The increasing SO4 trends at two springs are believed to be the result of anthropogenic factors. Total NO3 is increasing at six springs and decreasing at two. At many springs the total NO3 concentration is currently elevated above the concentrations found in the '50's, '60's, and early '70's.

8:30 AM GHY-3 Nitrate Concentrations in the Wekiva Groundwater Basin. DAVID J. TOTH, St. Johns River Water Management District, P. O. Box 1429, Palatka, Fl. 32178-1429. Nitrate plus nitrite N (NO3) concentrations have been measured in Wekiva Springs since 1961 (0.61 mg/l) and have increased during the late seventies and early eighties. In 1995, concentrations reached a maximum of 2.00 mg/l. Since 1995, NO3 concentrations have decreased. In 1999, the NO3 concentration at Wekiva Springs was measured at 1.30 mg/l. At this concentration Wekiva Springs was calculated to discharge 458 pounds or 84 tons of N/yr. In a previous investigation (Toth 1999), the St. Johns River Water Management District (SJRWMD) determined that the source of the nitrates were from animal waste and/or sewage. From that study background concentrations were determined to be below 0.2 mg/l. In an effort to better locate the source of the nitrates, SJRWMD sampled 50 sites for NO3 and 11 sites for isotopes (H^2, O^{18}, N^{15}, H^3, and He^3) in the Wekiva Groundwater Basin in 1999. The data suggest that the areas of the highest concentrations of NO3 (7.5 mg/l) do not contribute to the NO3 discharging from Wekiva Springs. However, the more locally developed flow of the Upper Floridan aquifer in the vicinity of the Spring results in a more direct influence and source of the nitrate contamination displayed at the Spring.

8:45 AM GHY-4 Impacts to Ground Water Quality in a Karst Environment Due to Urbanization and Agricultural Land-use Practices. GREGG W. JONES (1), DAVID J. DEWITT (2), KYLE M. CHAMPION, AND SAM B. UPCHURCH (3). (1) Southwest Florida Water Management District, Brooksville, Fl. (2) Southwest Florida Water Management District, Tampa, Fl, (3) ERM-South, Tampa, Fl. Springs are a major hydrologic feature in the SWFWMD, and discharge nearly 1.5 billion gallons of water per day from the Floridan aquifer. Many springs in the region have been experiencing increasing nitrate concentrations since the late 1960's. Eighty springs, sampled between 1991 and 1999, have nitrate concentrations that range from <0.01 mg/l to 3.1 mg/l. Springs in the SWFWMD discharge nearly 1,700 tons of nitrate each year from the Floridan aquifer to the coastal rivers and estuaries of the SWFWMD. More than 40 nitrogen isotope samples, collected at various springs, indicate that the nitrate discharging from the springs originated from the use of inorganic fertilizers near the springs. These fertilizers, applied in urban and agricultural land use settings (some 10-15 years ago) has impacted water quality in karst areas in west-central Florida. The correlation of population growth and increasing nitrate at the springs is evidence that non-point source pollution is affecting water quality in the region.

DYNAMICS OF WATER FLOW TO SPRINGS: (HYDROGEOLOGICAL ASPECTS)

9:00 AM GHY-5 Some Thoughts on Length and Time Scales of Conduit Flow to Springs. D. E. LOPER, Geophysical Fluid Dynamics Institute, Florida State University, Tallahassee. Springs in karstic settings are fed by a system of conduits which rapidly conveys flow from a broad watershed. In this talk, some simple steady scaling relations, relating conduit flow and rainfall recharge rate and spring discharge rate, will be presented and discussed. If time allows, the time-dependent behavior of water and contaminants will be quantified and discussed.

9:15 AM GHY-6 Predictor Wells to Estimate Spring Discharge, J.M. DUMEYER, Schreuder, Inc., 110 West Country Club Drive, Tampa, Fl, 32612. Most of the springs in Florida are measured only on an intermittent basis, due to a variety of physical constraints or lack of adequate measurement devices. Many of the coastal springs are influenced by tidal conditions and many other springs occur as submerged vents in a stream or river channel, which makes for difficult measuring conditions. In the early 1980s, the USGS began investigating the use of key monitor wells to correlate Floridan Aquifer water levels with spring discharge in order to calibrate groundwater flow models. The approach taken was to correlate by linear rrgression the daily water levels in monitor wells with samy day measured flow in an individual spring. Various time lags and tidal stage conditions were also evaluated. Those wells with good correlation (high r^2 value) were then used to predict the springflows for non-measured time periods. This method is currently used by the USGS to calculate the daily flows for Homosassa Springs in Citrus County and Weeki Wachee Springs in Hernando County. Similar methods have been used by the author to calculate the daily flows for Crystal Springs in Pasco County and Lithia Springs in Hillsborough County. This method provides a good means of adding springflow data to the hydrologic record.

9:30 AM GHY-7 New Concepts for Groundwater Modeling in the Floridan Aquifer. T.R. KINCAID AND T.J. HAZLETT, Hazlett-Kincaid, Inc., 204 South 7th Street, Akron PA 17501. Efforts to predict groundwater flow paths and velocities through karst aquifers are hindered by conceptual and numerical inadequacies. This paper presents a hydrologic conceptual model for saturated cave development and the results of a preliminary groundwater flow model of the Wakulla Spring catchment. The conceptual model shows that saturated caves can be classified in terms of their hydraulic function, as storage or flow dominant, and that the key variable controlling cave localization is the hydraulic gradient. The preliminary model of the Wakulla Spring catchment indicates that complicated cave patterns and K contrasts of 8-10 orders of magnitude can be explicitly modeled with sophisticated finite-element techniques producing superior predictive capabilities. Continuing efforts focus on the expansion and calibration of the flow model and the application to other basins

9:45 AM GHY-8 Timescales for Nitrate Contamination of Spring Waters. B.G. KATZ (1), J.K. BOHLKE (2), AND H.D. HORNSBY (3), (1) USGS, 227 N. Bronough St., Tallahassee, FL 32301, (2) USGS, 431 National Center, Reston, VA 20192, (3) SRWMD, County Road 49, Live Oak, Florida 32060. During the past 30 years, nitrate-N concentrations have increased from less than 1.0 to more than 5.0 mg/L in spring waters of the Suwannee River Basin in northern Florida. Naturally-occurring tracers, chlorofluoro-carbons, and tritium/helium-3 were used to estimate residence times of ground water discharging from selected springs and assess timescales of nitrate contamination. During 1997-99, 17 water samples were collected from 12 springs discharging from the Upper Floridan aquifer. Several flow-system models were used to explain different distributions of ground-water residence time from these tracers in this complex karst system. Ground water discharging from springs with low flows (1-10 ft^3/s) had high nitrate concentrations and residence times of 10 years or less, whereas springs with higher flows (>10 ft^3/s) tended to have low nitrate concentrations and groundwater residence times of 20 or more years.

10:00 AM GHY-9 Estimating Travel Time of Locally Derived Recharge in the Middle Suwannee River Basin Based on Water Quantity and Quality Changes. T. H. GREENHALGH, Florida Department of Environmental Protection, Mail Stop #3555, 2600 Blair Stone Road, Tallahassee 32399-2400. Two third magnitude springs and two river locations in the Middle Suwannee River basin were sampled biweekly from March through December 2000 in an attempt to bracket a local recharge event. Discrete metered parameters (conductivity, dissolved oxygen, pH, salinity and temperature), bottle samples, and spring discharge measurements were collected. Bottle samples from the river and springs were analyzed for color, nitrate-nitrogen, total phosphorus, potassium and sulfate. Additionally, spring samples were analyzed for multiple pesticides and volatile organic compounds. Dataloggers were deployed in the spring conduits to collect discrete metered parameter values every thirty minutes. In August, a trace level analytical methodology for select pesticides was employed. Subsequent analysis detected low level concentrations of the herbicides-atrazine and metolachlor in the spring samples. Unfortunately, drought conditions existed for most of the study which precluded obtaining a response to a significant recharge event.

10:15 AM BREAK

CHEMICAL, BIOLOGICAL AND OTHER FACTORS AFFECTING FLORIDA'S SPRINGS; THE SIGNIFICANCE OF SPRINGS TO SOCIETY

10:30 AM GHY-10 Chemistry, Biology, and Other Factors That Affect Florida's Springs: The Significance of Spring Changes to Society. SAM B. UPCHRUCH, Environmental Resources Management – Southeast, 3913 Riga Blvd., Tampa, FL 33619. Most of the springs currently experiencing changes that are perceived as being deleterious. For example, there is concern for rising nitrate concentrations in spring discharge because of potentials for algal growth and human health risks. Other springs are currently undergoing declines in discharge, and a few have already gone dry. Development and use for water supply or recreation may also alter the spring environment. While the consequences of these changes in water use, water quality, or land use are debatable, there is a growing concern that they are harmful to the spring environment. This paper will summarize the chemical, biological, and other changes that springs are presently undergoing. Each of the significant changes will be compared to possible consequences with respect to the spring and receiving water ecosystems and human use of the springs.

10:45 AM GHY-11 U Isotopes in the Waters of Northern Peninsular Florida. J.B. COWART AND J.K. OSMOND, Dept. of Geological Sciences, Florida State University, Tallahassee, 32306-4100. Analyses of the waters from a large number of springs and wells in northern peninsular Florida for uranium concentration and the alpha activity isotope ratio $^{234}U/^{238}U$ ("AR") have been carried out for a number of years. From these analyses a pattern has been discerned, namely that the waters from those areas which have had the confining layer of clays and sandy clays eroded away almost always have a relatively high U concentration and a low AR (1.00 or less) whereas those areas which still have the confining layer intact have a low U concentration and an AR greater than 1.00. The highest U concentrations and lowest ARs are often near the erosional boundary. This

11:00 AM GHY-12 Differences in Water Geochemistry of Springs, Leon and Wakulla Counties, Florida. HONGSHENG CAO, JAMES B. COWART, AND J. KEN OSMOND, Dept. of Geol. Sci., Florida State Univ. The water from deep Wakulla Springs has low strontium and uranium ratios and high uranium concentrations. The spring waters in Doris Drive, Myers Park, and Indian Head have high uranium and strontium ratios and low uranium concentrations. The major and trace element concentrations of groundwater from springs also show that the water source of three shallow springs is different from that of the deep Wakulla Springs. Generally, groundwaters from three shallow springs have lower major and trace element concentrations than those from the deep spring. Three shallow springs have lower concentrations of Na, Si, Ca, and Mg than Wakulla Springs. Wakulla Springs and three shallow springs demonstrate different patterns of trace element concentrations. Water samples from Wakulla Springs and Doris Drive spring have higher ratio of Ca/Sr than shallow springs in Myers Park and Indian Head.

11:15 AM GHY-13 Biology and Impact of a Stem Tip Mining Midge (Diptera: Chironomidae) on the Aquatic Weed Hydrilla (Hydrocharitaceae) at Crystal River, Florida. J.P. CUDA (1), AND T.D. CENTER (2), (1) University of Florida, Gainesville 32611-0620, (2) USDA, ARS Invasive Plant Research Laboratory, Ft. Lauderdale 33314. The larval stage of a midge that was recently identified as *Cricotopus lebetis* Sublette was discovered attacking the shoot tips of hydrilla, *Hydrilla verticillata* (L.F.) Royle, in the Kings Bay/Crystal River watershed, a coastal spring-fed freshwater ecosystem. Field surveys and laboratory experiments demonstrated that developing larvae of *C. lebetis* severely injured or killed the plant's growing tips, preventing new hydrilla stems from reaching the surface of the water column. This type of damage is desirable for managing hydrilla infestations because it could eliminate most of the adverse effects caused by the formation of the dense surface mats. By experimentally demonstrating the midge is capable of suppressing hydrilla shoot growth, its potential as a biological control agent of hydrilla was confirmed.

GEOLOGY/HYDROLOGY

11:30 AM GHY-14 Geologic Framework and Recharge of the Sandstone Aquifer in Southwestern Florida. T. M. MISSIMER AND W. K. MARTIN, CDM/Missimer International, Inc., 8140 College Parkway, Suite 202, Fort Myers 33919. The Sandstone Aquifer occurs within the late Miocene-age Peace River Formation in southwestern Florida. The aquifer is currently defined to be in the Intermediate Aquifer System. New geologic information shows that the aquifer contains multiple production zones separated by muds and clays that provide varying degrees of confinement between the zones. The aquifer is hydraulically connected directly to the overlying Surficial Aquifer System in southwestern Hendry County and northeastern Collier County. The aquifer is directly recharged in some of these areas and also by leakage through confining beds throughout much of the region. Because the Sandstone Aquifer is directly connected to the Surficial Aquifer System and has similar water quality characteristics, it should be classified as part of the Surficial Aquifer System rather than the Intermediate Aquifer System.

11:45 AM GHY-15 Geology and Paleontology of a Lower Caloosahatchee Formation Deposit at Lehigh Acres, Florida. T.M. MISSIMER AND A.E. TOBIAS, CDM/Missimer International, Inc., 8140 College Parkway, Suite 202, Fort Myers 33919. A one meter deep channel incised into the Tamiami Formation at Lehigh Acres (Sec.10, T44S, R27E) in Lee County contains an assemblage of Blancan-age vertebrate and molluscan fauna. The base of the deposit contains vertebrate fossils and a diverse assemblage of molluscan fauna. The middle of the deposit contains a diverse assemblage of mollusks and corals. The predominant molluscan species are *Turritella perattenuata* Heilprin, *Conus adversarius tryoni* Heilprin, *Chione cancellata* (Linnaeus), and *Carditamera arata* (Conrad). The corals include *Solenastrea hyades* (Dana), *Trachyphyllia* sp., *Porites porites* (Pallas), and *Placocyathus costatus* (Duncan). The top of the deposit contains a bed predominated by the gastropod *Pyrazus scalatus* (Heilprin) and is capped by a thin freshwater limestone containing the mollusk *Helisoma disstoni* (Dall). The Blancan assemblage is believed to be between 2.5 to 2 Ma in age and correlates well with the basal

Caloosahatchee Formation of Captiva Island that had a maximum estimated age of about 2.14 Ma (Missimer).

12:00 PM BUSINESS MEETING: GEOLOGICAL AND HYDROLOGICAL SCIENCES
RICK COPELAND,presiding

FAS POSTER SESSION (GHY)
FRIDAY, 7:55 AM – 4:15 PM
LEWIS FIRST FLOOR HALLWAY

POS-1 Aquatic Biota and Water Chemistry of Illinois Caves and Springs: Problems and Management. MARK J. WETZEL, STEVEN J. TAYLOR, AND DONALD W. WEBB. Illinois Natural History Survey, Center for Biodiversity, 172 Natural Resources Building, MC-652, 607 E. Peabody Drive, Champaign, Illinois 61820-6917.

FRIDAY 2:30 PM LEWIS 206
SESSION B
RICK COPELAND, FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION, presiding

GEOLOGY/HYDROLOGY FILMS

2:30 PM GHY-16 *Polluting the Fountain of Youth* (50 minutes). This film was originally produced for, and aired on, the Discovery Channel. The film documents the natural wonders of Ichetucknee Springs, located in north-central Florida, and the current human activities that are threatening to pollute it.

3:20 PM BREAK

3:30 PM GHY-17 *Freshwater Caves* (30 minutes). This film was produced by Karst Productions, Inc. From underwater, the film lets the viewer visit a series of unique and varied underwater springs and caves located in the southeastern United States. Included is a visit into the passage of Wakulla Springs, a huge spring/cave system located in north Florida.

4:00 PM GHY-18 *Bird Sink: Our Water at Risk* (15 minutes). This film was produced by a private individual interested in the potential pollution of an individual spring/sink system located just outside of

Tallahassee, Florida. Viewed from both above and below the water surface, the film documents the pollution of the sink.

MEDICAL SCIENCES

SATURDAY 9:00 AM LEWIS 203
ROSEANN S. WHITE, UNIVERSITY OF CENTRAL FLORIDA, presiding

9:00AM MED-1 Comparative Analysis Of Anti-Saccharomyces cervisiae Antibodies (ASCA) And *Mycobacterium avium subsp. paratuberculosis* Recombinant Antigens For Diagnosis Of Crohn's Disease. S. A. NASER and I. SHAFRAN. Department of Molecular Biology and Microbiology. University of Central Florida, Orlando, 32816. Numerous studies have confirmed the utility of ASCA as a serological marker for Crohn's disease (CD). Recent investigations have identified the utility of another potential CD diagnostic serum marker, p35 and p36 recombinant antigen from *Mycobacterium avium subsp. Paratuberculosis* (MAP). Serum samples were obtained from 60 CD patients. The sera samples were sent to Prometheus Laboratories (CA) to determine the IgA and IgG ASCA titers. The serologic response to p35 and p36 were analyzed by Western blotting at the University of Central Florida. The ASCA titer levels for IgA and/or IgG were positive for 61.7% (36/60) of CS patients. The p35 and/or p36 recombinant clones were positive for 86.7% (52/60) of CD patients. The 24 CD patients not detected by ASCA were identified as positive by the p35 and/or p36 recombinant clones in 87.5% (21/24) of those CD patients missed by ASCA. The 9 CD patients not detected by p35 and/or p36 were identified by the ASCA serologic markers in 62.5% (5/8) of those CD patients missed by p35 and p36. This investigation further establishes the utility of p35 and p36 recombinant clones for the diagnosis of CD. These results also reveal added evidence to demonstrate the complimentary role that ASCA may have with p35 and p36 for increasing the sensitivity and specificity of these serologic tests. Larger studies are needed to investigate the combined use of these serologic markers for the diagnosis of CD and as predictive markers to facilitate the development of treatment strategies.

9:15AM MED-2 Rationale for the Negative Effect of Smoking Cigarettes on Crohn's Disease Patients. S. A. NASER AND G. GHOBRIAL. Department of Molecular Biology and Microbiology. University of Central Florida, Orlando, 32816. It is well established that smoking cigarettes is associated with Crohn's disease (CD) and that non-smoking is associated with ulcerative colitis (UC). Although, it is well accepted that smoking cigarettes has a negative effect on the course of CD, there has been limited studies that may adequately explains the observed clinical patterns. On the contrary to UC, CD has been associated with *Mycobacterium avium subsp. paratuberculosis* (MAP). Nicotine, a naturally occurring alkaloid, is considered to be the addictive and most pharmacologically active substance among the many compounds present in tobacco products. Nicotine at final concentrations of 0 to 50 ug/ml was tested against MAP in Bactec bottles supplemented with OADC and Mycobactin J. The Growth Index (GI) was read daily using the Bactec 460 TB analyzer. The MIC_{50} and MIC90 were 1.5 and 3.0 ug/ml, respectively. This MIC_{90} is significantly low compared to normal nicotine level in saliva of those using tobacco-based products (70 to 1560 ug/ml). This indicates that MAP is susceptible to nicotine. The data suggest that MAP residing in ulcerated mucosal cells may be affected by the high concentration of nicotine in these patients. Consequently, numerous antigens or group of antigens in which some have strong cross reactivity with intestinal proteins may lead to strong inflammatory response. Furthermore, the acute CD presentations in CD smokers may be directly related to the presence of MAP in their tissue compared to those smokers with or without UC.

9:30AM MED-3 In Vitro Evaluation of Nicotine Effect on Mycobacterial Growth. S. A. NASER AND G. GHOBRIAL. Department of Molecular Biology and Microbiology. University of Central Florida, 32816. The naturally occurring alkaloid, nicotine, is considered to be the addictive and most pharmacologically active substance among the many compounds present in tobacco products. The effect of nicotine on microbial activity has not been well investigated especially on those that are part of the microbiota or those causing gastroenteritis or pulmonary diseases. Nicotine at final concentrations of 0.75, 1.25, 1.75, 2.25, 2.75, 3.25, 3.75, 4.25, 8.5, 17.0 and 50 ug/ml was tested against *Mycobacterium avium* subsp. *avium*, *M. avium* subsp. *paratuberculosis*, *M. intracellulare*, *M. smegamtis* and *M. tuberculosis* strains H3RVa and ATCC 25777. Surprisingly, all microorganisms were susceptible to nicotine with *M. tuberculosis* strains as most susceptible and *M. intracellulare* as least susceptible. The MIC_{50} ranged between 0.75 to 2.0 ug/ml and MIC_{90} ranged between 2.0 to 3.0 ug/ml. The effect of nicotine at least on *M. tuberculosis* growth was determined to be cidal. The MIC_{90} reported here is significantly low compared to normal nicotine level in saliva of those using tobacco-based products (70 to 1560 ug/m). The data suggest a potential therapeutic application for mycobacterial-caused disease. The data is complimentary to recent reports suggesting similar application of nicotine for treatment of cancer and other diseases.

9:45 AM MED-4 Detection of Paget cells by Zirconyl Hematoxylin. A. A. SMITH (1), T. M. SILVER (2), AND B. E. KIPREOS (3), (1) Barry University, Miami Shores, FL 33161, (2) Virginia Commonwealth University, Richmond, VA, (3) Hunter Holmes McGuire Veteran's Medical Center, Richmond, VA. Zirconyl hematoxylin selectively stains the Paget cells of extramammary Paget's disease. It stains no other cells in the skin. Zirconyl hematoxylin might be useful in determining the extent of surgery necessary for the excision of extramammary Paget's disease.

10:00 AM BREAK

10:15 AM MED-5 Purificaton of the Major Bahia Grass Pollen Allergen and Comparison with PH1 pI, the Major Timothy Grass Pollen Allergen. J. WHITE, A. MAJIDI, G. GHOBRIAL, S. NASER, M. SWEENEY, AND R. WHITE, University of Central Florida, Orlando, 32816. Pollen proteins of Bahia grass were extracted using ammonium bicarbonate at pH 7.2. These water soluble proteins of Bahia pollen were partially purified using isoelectric focusing. The fractions containing the 32 kD major allergen of Bahia grass pollen were refocused to purify this component. This 32kD component was reactive with IgE from sera of patients skin test positive to Bahia. The 20 N-terminal amino acids were sequenced, and the degree of sequence homology with other proteins was determined. The major bahia allergen, Pas n 1, showed 63% sequence homology with Phl pI, the major Timothy grass allergen. Western blot analysis of this 32 kD protein of Bahia was performed using monoclonal antibody to the group I allergen of Timothy grass. The 32 kD component of Bahia pollen was reactive with the Timothy grass group I allergen demonstrating cross-reactivity between Bahia and Timothy grass pollen proteins. Western blot analysis of the 32 kD protein was also performed using monoclonal antibodies to group V and group XIII timothy allergens.

10:30 AM MED-6 Body Piercing and Medical Complications. E.T. HAYS, A. DALMAZZO, M. DEJUSTE, AND A. LONG. SNHS, Barry University, Miami, 33161. In the past five to ten years, body piercing in areas other than the ears have become quite popular among young people. This form of body art even extends to genital piercings that are considered to enhance sexual arousal and pleasure. Medical journals have raised concern about this "art form" because of medical complications that have been seen as a result of the "art". The purpose of our study was to assess the prevalence of body piercings in college students with comparisons being made among graduate and undergraduate biology majors and freshman and non-freshman non-science students. Our results indicate that few students admit to having genital piercings although body piercings are prevalent amongst most of the groups studied. Medical complications have been experienced by some.

10:45 AM BUSINESS MEETING: MEDICAL SCIENCES
ROSEANN WHITE, presiding

JOINT MEETING
PHYSICS AND SPACE SCIENCES SECTION
ENGINEERING SCIENCES SECTION

FRIDAY 8:55 AM LEWIS 306
SESSION A
HAMID RASSOUL, FLORIDA INSTITUTE OF TECHNOLOGY, presiding

8:55 AM WELCOME AND ORGANIZATION

9:00 AM PSS-1 Quasars, Blazars, and Other Active Galactic Nuclei: an Overview. S. CLEMENTS, Florida Institute of Technology, Physics and Space Sciences, 150 West University Blvd., Melbourne 32901. Among the most distant objects in the universe, active galactic nuclei (AGN) have been slowly giving up their secrets. Observations that at first were puzzling eventually led to an elegant working model. Various types of AGN will be discussed in relation to this model. Observations of these objects not only teach us about the objects themselves, but also allow us to probe the distant youthful universe, and thus help us to establish our place among the cosmos.

9:15 AM PSS-2 Microvariability of Active Galactic Nuclei. G. KESHISHIAN, S. CLEMENTS, A. HIRSCHMANN, A. JENKS, AND Y. TORRES, Florida Institute of Technology, Physics and Space Science, 150 West University Blvd., Melbourne 32901. Active galactic nuclei (AGN) vary in brightness on timescales ranging from hours to years. Multiyear variations are evident in long-term optical and radio light curves. Short-term microvariability occurs on timescales of a few hours or less. Observations of variability provide important constraints on models for these objects. We present microvariability observations of some selected AGN and discuss our findings in relation to various models.

9:30 AM PSS-3 Searching for the Origin of Inertia. P. COLTHARP, M. MOLLOY, AND H. HICKMAN, Science Department, Hillsborough Community College, P.O. Box 30030, Tampa 33630. Certain solutions to Einstein's equations of General Relativity suggest that the past and the future actually exist. If that is true, then it may be possible for objects in the past and future to exert forces on objects in the present. Here we look at the hypothetical self-force exerted on a point charge in the present, by all of its past and future "editions". A naive replacement of the Pythagorean distance in the denominator of Coulomb's Law, by the Minkowski interval for flat space-time, leads to the following results: In terms of self-force, only a few microseconds into the past or future can have an appreciable affect on the present. If the charge moves with constant velocity, then the net self-force equals zero. If the charge is being accelerated, then the net self-force is not equal to zero. The out of balance self-force for the accelerated case brings to mind the phenomena of inertia.

9:45 AM PSS-4 Search for the Standard Model's Higgs Boson. G. BAKSAY. The Standard Model proposes that there is another field not yet observed, a field that is almost indistinguishable from empty space. We call this the Higgs field. The so-called Higgs mechanism suggests that particles acquire mass by interacting with this force field which is present. The discovery of an associated particle or particles, the Higgs boson(s), would be the evidence for this field. In the data collected with the L3 and two other detectors at LEP at sqrt (S) = 206.6 GeV excess of events above background compatible with a Standard Model Higgs boson of mass 114.5 GeV were found. These results and their implications would be focused on in this talk.

10:00 AM PSS-5 Developing and Testing of Position Monitoring System for the Muon Chambers of the CMS Experiment at Cern. V.VESZPREMI, Florida Institute of Technology, 150 West University Blvd., Melbourne, FL 32901.One of the most important goals of the CMS experiment is to find the Higgs boson predicted by the Standard Model. This research is partially based on the detection of muons produced from decay of Higgs particle. To reach a good precision in tracking muons, it is required to know the position of the Muon Chambers of the CMS detector with a precision at least equal to the intrinsic precision of the chambers. For this purpose, the chambers will be supplied an optical system composed of LED's and CCD cameras. This optical system will be capable of continuously observing the movement of any part of the Muon System. The measurements will be controlled and processed on-line by a special program called SimulGeo that simulates the system and provides more precise measurements of the locations.

10:15 AM BREAK

10:30 AM PSS-6 Special Relativity and the Magnetic Field. A. DREW, C. WARD, AND H. HICKMAN, Science Department, Hillsborough Community College, P.O. Box 30030, Tampa 33630. The idea that the magnetic field is actually a relativistic transformation of the electric field is one of the cornerstones of modern Electrodynamics. An expository model proposed by Max Born, uses Special Relativity to analyze a single point charge moving parallel to a current carrying “wire”. A laboratory frame observer sees a magnetic field emanating from the wire and exerting a force on the moving point charge. An observer riding on the charge however, sees only an electric field causing the force. We point out that the magnetic field and the electric field are shielded quite differently, and that it might be possible to shield out the force in the electric field frame, but let it through in the magnetic field frame. That would be a serious inconsistency since this particular force cannot be zero from one point of view and non-zero from another point of view.

10:45 AM PSS-7 Multiple Field Lines. ROBERT W. FLYNN, Physics Department, University of South Florida, Tampa, Florida 33620. The electric field of any charge distribution can be expressed as a sum of the fields due to a point charge, a dipole, a quadrupole, an octupole etc. The equations for the electric field lines of a point charge, dipole and quadrupole are well known. Those for higher order multipoles are rarely seen. This paper gives a general solution for the field lines of any order multipole.

11:00 AM PSS-8 Performance of Geometric Anti-spring Filter (GASF) for Seismic Attenuation in Advanced Gravitational Wave Detectors. H. TARIQ (1) and R. DESALVO (2), (1) Florida Institute of Technology, Florida, (2) California Institute of Technology, California, LIGO Project, SAS TEAM. The frequency band of some interesting and possibly frequent gravitational wave events span a low frequency range of up to 10Hz. The main limit in this band is seismic noise, which requires a good isolation system to suppress it down to the thermal noise level. We are developing a Seismic Attenuation System (SAS) for new generation of Gravitational wave detectors to realize this low frequency isolation performance. The SAS, basically a passive mechanical filter, is designed to provide low frequency isolation starting at 10-100 mHZ for all the degrees of freedom. The main obstacle for the isolator is to support heavy test masses, while retaining the softness of the system for low frequency attenuation, which is achieved by a Geometric Anti-Spring Filter (GASF) technique. The GASF consists of cantilever blades linked to a load, using a geometric anti-spring effect. It can achieve an ultra low resonant frequency

(~ 100 mHZ), supporting a mass of few hundred kg. The mechanical setup and the materials used are especially selected to reduce creep, excess noise, and high vacuum compatibility. The prototype filters have been fabricated already, and their isolation performance measured. These results would be focused on in this talk.

11:15 AM PSS-9 Quantized Time Harmonic Forced Oscillations of a Load. PETER GREEN, Florida Institute of Technology, Melbourne, FL 32901. Given a gravitational field at field point $\vec{r}(t)$ given by $\vec{g}(\vec{r}(t)) = -(GM/[\vec{r}(t)]^2)\cdot\hat{r}$ and due to a non-spinning perfectly spherical and homogenous mass distribution of mass M and radius R, we show that application of the radial time-harmonic force $\vec{F}(\omega,t) = mg\cdot\left(1 - e^{i\omega t'}\right)\cdot\hat{r}$ to a load mass m located at $\vec{r}(t) > R$ can produce the condition $\left\langle \vec{r}(t) \right\rangle_T$ = constant if the driving frequencies ω are quantized and given by $\omega_n = \frac{n\pi c}{R}$ where c is the speed of light in vacuum and n = 1,2,3... integer. The so-called retarded time t' = t – R/c is used and the notation $\left\langle \vec{r}(t) \right\rangle_T$ indicates a time-average value. The mechanical power associated with the load support is calculated and its time-average value is shown to be similarly quantized and directly proportional to the load mass, the square of the g-field strength, and the expression $\frac{\sqrt{2+\cos n\pi}}{n}$. The gravitational radiation due to the forced oscillations of the load is also calculated and shown to be non-zero but insignificant for driving frequencies below several gigahertz.

11:30 AM PSS-10 The Forerunners of the Discovery of Neutron. LEO SZILARD AND GEORGE HEVESY, LASZLO KOVACS, Florida Institute of Technology, 150 West University Blvd., Melbourne, Florida 32901. Leo Szilard and Nobel laureate George de Hevesy were two successful scientists of Hungarian origin, mainly famous and known for their later results. This presentation aims to investigate their first connections to radioactivity, where though working on different projects, they had a lot in common. The presentation deals with an interesting set of events in their work, namely that they tended to be very close to the elementary discoveries of radioactivity, still they failed to succeed in those primary discoveries due to external reasons. Our purpose is to show how this *bad luck* helped them to achieve serious results in later applications that were all based on the phenomena they tended to fail to discover.

11:45 AM PSS-11 Engineering Principles Applied to the Atom. R. W. BECKWITH and A. P. CRAIG, Beckwith Electric Company Research Division, 6190-118th Ave. N., Largo, FL 33773-3724. The three Euclidean dimensions, the time dimension, the electric field dimension, and the magnetic field dimension all are orthogonal. A far attractive force between all atoms and a near repelling force from all atoms form a force model of the universe from the smallest dimension within the atom to the ends of the universe. Time is held as without end with the universe always existing. Gravity as a separate force is refuted. An energy balance example of the transmutation of N14 into C14 and decay of C14 back to N14 is given. A small but significant imbalance in energy is attributed to the release of neutrinos by C14 decay. This alternative engineering theory challenges both quantum mechanics and the unified field theory.

FRIDAY 2:30 PM LEWIS 306
SESSION B
HAMID RASSOUL, FLORIDA INSTITUTE OF TECHNOLOGY, presiding

2:30 PM PSS-12 Characteristics of Optical Emissions and Particle Precipitation of Great Aurorae. HAMID RASSOUL, Florida Institute of Technology, Melbourne, Florida 32901. A geomagnetic storm is characterized by a variation of the Earth's magnetic field usually associated with a disturbance on the sun, such as a solar flare or a coronal mass ejection. During such a storm a large amount of energy flows into the upper atmosphere. This energy is globally transmitted to the thermosphere and ionosphere, giving rise to various phenomena such as changes in ionization, optical excitation, heating, atmospheric dynamics, composition, and thermal structure. This presentation focuses on the characteristics of optical emission and particle precipitation in the so-called great aurorae – the enhanced atmospheric optical emissions at low and mid latitude regions that result from particle precipitation originated from the storm-time Van Allen radiation belt. With detailed optical and field observations, we have estimated the average energy of the precipitating particles, their energy deposition rate, and their ionization production. In addition, by comparing the optical data with ground-based magnetometer data, some constraints of the storm-time current system are investigated.

2:45 PM PSS-13 Intensity of Magnetic Storms as Measured by Ring Current Intensifaction. STELLA KOUMI (1), HAMID RASSOUL (1), IOANNIS DAGLIS (2), (1) Florida Institute of Technology, Florida; (2) National Observatory of Athens, Greece. The most widely used measure of storm intensity is the Dst index, which is constructed from magnetograms of several low-latitude stations, and involves deviations in the horizontal H+ component of the geomagnetic field from quiet-time values. This we call the "observed" Dst index. In this paper we compare the "observed" Dst with a "proxy" Dst, which is calculated from energetic ion measurements of the ring current, using the Dessler - Parker - Sckopke relation, and which we call the "estimated" Dst index. We examine the case of June 5, 1991(and July 8-13) intense magnetic storms, which reached observed minimum Dst levels of --200 to --270 nT. We use energetic ion measurements from the Combined Release and Radiation Effects Satellite (CRRES) and the Dessler- Parker - Sckopke relation, in order to derive the "estimated" Dst index due to the ring current. The comparison of "observed" and "estimated" Dst reveals differences, which are attributed to two factors: the inherent limitations of the particle measurements, and the influence of magnetospheric current systems other than the ring current on ground geomagnetic disturbances. For the first factor we should mention that the particular matrix rates of the Magnetospheric Ion Composition Spectrometer (MICS), where the particle data originate, have a lower energy threshold of approximately 50 keV. Therefore O+ and H+ ions with lower energies are not detected. If a significant part of the ring current was contained in lower energies (which is quite reasonable), we conclude that the MICS measurements do not accurately represent the ring current strength. The paper presents the results of the comparison and discusses their implications.

3:00 PM PSS-14 Waves in Space: Observation of PC 3 at Mid and Low Latitudes Using Measure Array. M. WERNER and D. MITSAKOS, Florida Institute of Technology, 150 W. University Blvd., Melbourne, 32901. The magnetospheric plasma, by definition, is permeated by the geomagnetic field and thus can support various kinds of waves that are at home in a magneto-plasma. This work presents a general classification of various waves in geospace, and then it focuses on understanding the nature of PC 3 waves – a regular and continuos micropulsation with a nominal period of 10-45 seconds in the earth's magnetic field. We will present our observations of these magnetospheric waves from mid and low latitude sites using MEASURE array. The study investigates various parameters of PC waves for September 1999 (Space Weather Month). For each MEASURE station, these include the start and stop time of waves, frequency, amplitude, and polarization of waves. Idea is to compare timing and characteristics of waves as a function of latitude and local time. In addition, we have attempted to identify differences in waves between quiet times and during storm intervals using magnetospheric indices of Kp and DST to select different intervals.

3:15 PM PSS-15 Characterization of Dayside Magnetospheric ULF Waves. PAUL MARTIN, Florida Institute of Technology, Melbourne, Fl 32901. This study investigates the statistical characteristics of dayside Pi2 pulsation observed along the 210 magnetic meridian, for 13 distinct, isolated substorm events during the year 1995. The following results were found: Pi2 pulsation on the nightside have predominance of left-handed polarization, dayside Pi2's have a phase difference between the H and D components generally proportional to the mean local time, wave power of dayside Pi2's in the H component has a peak around local noon, frequency range of the fundamental wave is 9-30 mHz with a dominant frequency of 17-24 mHz. These observations support the magnetospheric cavity model for the excitation of dayside Pi2 pulsation at low latitudes.

3:30 PM PSS-16 ULF Waves at the Plasmapause Using CRRES Data. ROBERT SCOTT. Florida Institute of Technology, Melbourne, FL 32901. Knowledge of the type and characteristics of the waves near the plasmapause offer insight into the modes of energy transport from the hot, tenuous plasma of the magnetosphere to the cold, dense plasma of the earth's plasmasphere. The sharp density gradient of the plasmapause offers a unique structure in which to study ULF waves. CRRES magnetometer data is used to determine the characteristics of ULF waves before, during, and exiting the plasmapause encounters. Wave characteristics such as frequency and amplitude are investigated. Poynting flux will be compared during the CRRES satellite's transition through the plasmapause. Twenty plasmapauses featuring a classic density gradient (knee) are inspected for ULF wave properties. Twenty plasmapauses displaying no sharp density gradient are inspected and the wave properties are compared.

3:45 PM BREAK

4:00 PM PSS-17 Sky-camera and UV Monitoring Project. C. HENDERSON and M. MIKULEC, Florida Institute of Technology, Melbourne, FL 32901. The need for highly calibrated surface UV flux measurements is due to the recognition that ozone depletion induced by human activity could lead to increase surface UV fluxes. Atmospheric research has shown conclusively that total ozone amounts have been decreasing over much of the Earth's surface due to increased concentrations of industrially produced halogens in the atmosphere. However, ground-based data sets do not confirm a long-term increase of surface UV flux. To assist an international effort to answer this puzzle, Florida Tech has developed a surface UV monitoring site that hosts a broadband solar UV monitoring system and a digital all-sky camera. The digital all-sky camera is needed to verify solar zenith angle and help determine cloud cover and aerosol (smoke, haze, sea salt etc.) concentrations. These data are vital parameters needed to make sense of long-term UV flux measurements. This talk presents a brief account of the driving science and reports on the first phase of the deployment of the model 440A Total Sky imager and UVB-1 Ultraviolet Pyranometer.

4:15 PM PSS-18 Engineering Appropriate Lightning Protection for the Twenty-first Century. MARK DRABKIN and TERRY TUCKER, Lightning Eliminators and Consultants, Inc., 6687 Arapahoe Road, Boulder, CO 80303. The two hundred-year-old method of using a Franklin Rod to collect the awesome energy of lightning and divert it to earth is a fundamentally unsound method of protecting sensitive electronics today. Engineering a method of prevention is a much more appropriate method for the 21st Century.

4:30 PM PSS-19 Electrical Resistivity Measurement for Site Evaluation. RAMANUJA C. KANNAN, R. C. Kannan & Associates, Inc. Largo, FL. Electrical resistivity test has played a very important role in profiling subsurface strata in numerous sinkhole-related studies. As compared to geophysical methods, resistivity measurement has become reliable, fast, accurate and even economical. While numerous geophysical testing methods are available for subsurface profiling, the standard penetration test remains the choice of engineers for the design of foundations. Our experience indicates that electrical resistivity test is the most affordable and reliable method of mapping in Florida's karst terrain and a very valuable tool in planning further exploratory borings. Presence of solution activity, void spaces in the limestone formation and ground subsidence caused by the solution activity have been linked to settlements in structures. With the use of electrical resistivity and tomography, anomalous zones could be better identified and standard penetration tests could be conducted at these locations. Electrical resistivity testing is also useful in preliminary mapping of large tracts, in locating potential sources of fill and in the site development process. Resistivity tests have also been used in defining contamination plumes without invasive sampling methods. Case studies discussed herein establish that electrical resistivity test provides the most valuable site characterization in geotechnical investigations. Using electrical resistivity, we have substantially reduced the uncertainty in defining the subsurface strata, in identifying the problem areas, in designing appropriate foundations and in designing foundation remedies for sinkhole-affected structures.

4:45 PM BUSINESS MEETING: Joint Meeting of PHYSICS AND SPACE SCIENCES SECTION & ENGINEERING SCIENCES SECTION
HAMID RASSOUL, presiding

SCIENCE TEACHING

FRIDAY 9:00 AM LEWIS 307
SESSION A
RANDY CRISS, SAINT LEO UNIVERSITY, presiding

9:00 AM TCH-1 Computer in the Mathematics Classroom: Mode vs. Tool. J. A. WHITE, Saint Leo University, Dept. of Mathematics and Science MC 2188, 33701 St. Rd. 52, Saint Leo, FL 33574. This paper reflects findings of a study that investigated the extent to which integration of computers in mathematics instruction affects student attitudes and performance. An ANOVA revealed a significant decline in attitude toward mathematics for students receiving computer-based instruction. Results are critical to faculty and institutions of higher education as decisions aegarding future methods for incorporating technology into mathematics instruction.

9:15 AM TCH-2 Teaching Calculus in a Small University. SIAMACK BONDARI AND J. A. WHITE, Saint Leo University, Dept. of Mathematics and Science, P.O. Box 6665, Saint Leo, FL 33574. Many of the students who have just passed college algebra and trigonometry face a difficult challenge when they move on to take calculus. Some of these students are not well prepared for the new course and others have a hard time adjusting to the big jump from pre-calculus to calculus. The problem is even worse in small universities where only a very small percentage of students are required to take calculus and almost all of them take it as a terminal course. Furthermore, as strange as it may sound, the small class size of under six students often works in the instructor's disadvantage. Instructors at such settings must come up with innovative ideas to keep the students interested in new material without spending too much time referring back to pre-calculus topics students are supposed to already know. Instructors must use good time management, appropriate use of technology, and possibly cover the material in a slightly different order from the traditional calculus book to succeed.

9:30 AM TCH-3 Mathematical Properties of Guitar Fret Placement. THOMAS E. RUTENKROGER, Valencia Community College, P. O. Box 3028, Orlando, FL 32802. The purpose of this presentation is to provide insight into the development of the basic algorithms which dictate the fret placement, and design of modern guitars. The applications are directed toward use in the mathematics or physical science classroom. The mathematical models are exponential in nature, and based on both empirical and analytical methods of analysis. An emphasis is placed on a function oriented approach correlated to utilizing both graphical and tabular approaches. The use of technology in classroom presentation is encouraged and the TI 83 calculator (or any computer format supporting tables) is recommended.

9:45 AM TCH-4 Teaching Science Through Ethnobotany: Unifying Theme in Science Education. WILLIAM H. CHROUSER, Warner Southern College, Dept. of Natural Science and Mathematics, 151 Taylor Street, Lake Wales, FL 33853. The presenter will relate stories of how primitive men and women must have been "ethnobotanists" due to necessity. They classified plants according to uses. Ethnobotany is defined by several general categories and separated into several subsciences. The many ways plants are used by societies are handled through a discussion of the following questions; "What good is this plant anyway?", "How did/do primitive societies use plant parts for maintaining life processes?", and "What compound in this plant caused a particular medical action?". A discussion about the integration of the following aspects related to ethnobotany will include: (1) Food, (2) Medicine (including the chemistry of medicine), (3) Fiber (identification of plants, morphology of where the fibers grow), (4) Nutrition, (5) Shelter (materials, characteristics), (6) Conservation, (7) Agricultural food, (8) History, (9) Ecology, (10) Archaeology, (11) Plant taxonomy, (12) Plant anatomy/morphology. This session will close with a discussion of how educators might use strategies of ethnobotany in an integrated science curriculum

10:00 AM TCH-5 Teaching Science through Storytelling and Humor. WILLIAM H. CHROUSER, Warner Southern College, Dept. of Natural Science and Mathematics, 151 Taylor Street, Lake Wales, FL 33853. Stories and storytelling have been employed for centuries to assist people in remembering simple and complex scientific concepts. A brief explanation and discussion of the benefactors of stories are conveyed to reinforce science concepts. After the significance of stories is justified, several will be modeled. The need for humor in the classroom is verified. Several techniques are examined and modeled. Participants are invited to exhibit some humor techniques of their own. Participants are given suggestions on how to write their own narratives and how to enthuse students to write their own.

10:15 AM BREAK

10:30 AM TCH-6 Science Teaching and Education. AL HALL, Tallahassee Scientific Society, 4335 Sherborne Road, Tallahassee, FL 32303. This paper is an enhancement of a related presentation in 1998 entitled "Science Education in Transition: A Procedural Blueprint". Questions arising from that presentation indicated the need to provide more detailed proposals for the transition from the current curricula used for teaching science and mathematics to the recommended program. Portions of the previous presentation are included , and suggestions for the transition given in detail, using actual timetables from Leon County high schools. These details also provide for the special circumstances presented by the new "4x4" program used in some schools.

10:45 AM TCH-7 Statewide Trends in Science Education, K-12. JAY FELICIANI, District School Board of Pasco County, 7227 Land O'Lakes Blvd., Land O'Lakes, FL 34639-9900. As Supervisor of Science for Pasco County Schools and the current president for the Florida Association of Science Supervisors, Jay will present some of the challenges facing science educators as they meet the Sunshine State Standards. Topics in this discussion will include the status of science courses in a K-12 system, content needs of current and prospective science teachers, and teacher attitudes toward the integration of sciences.

11:00 AM TCH-8 Assessing the Learning Outcomes of an Interdisciplinary Science Course. I. BARTSCH (1) AND R. POTTER (2), (1) Dept. of Women's Studies, University of South Florida, Tampa, FL 33620, (2) Dept. of Chemistry, University of South Florida, Tampa, FL 33620. There is a recognized need to reform science education particularly when it involves the training of teachers in science, math, and technology. Frequently, students who are not science majors lack the confidence to pursue more traditional natural science classes, yet everyone requires a basic understanding of scientific principles and processes in order to function effectively as citizens in our society. In Region IV, an interdisciplinary science sequence exists and is being delivered on several campuses. However, there is resistance to innovative courses at a number of levels including questions about lack of rigor enough and whether understanding of the material is truly enhanced when it is presented in a contextual format. Several forms of evaluation are being conducted in conjunction with the interdisciplinary course offered in Region IV to demonstrate that students not only learn science concepts but gain an appreciation for science. Student attitudes and interest in science following this interdisciplinary course are being measured and compared with the perspectives of students enrolled in traditional science classes.

11:15 AM TCH-9 Cooperative Learning in Science for College Non-Science Majors. KENNETH D. LASER AND MARY KAY CASSANI, Edison Community College, Division of Health/Sciences, 8099 College Parkway S.W., Ft. Myers, FL 33919. Edison Community College has redesigned their 2 semester course for non-science majors, 25% of whom are Elementary Science education majors. These 2-3 credit courses are interdisciplinary in nature, that fosters science literacy through experiential, co-operative learning, instead of "learning" science as a collection of memorized facts accompanied by a prescribed observational lab experience. The redesigned curriculum, Foundations of Interdisciplinary Science for Education, is a 2 semester sequential, combined lecture and laboratory course open to all non-science majors to fulfill the general science requirement. Chemistry and biology concepts are addressed in the first semester, followed by earth science, astronomy, and physics concepts in the second semester. The effectiveness of this course is currently being evaluated by ECC and FGCU.

11:30 AM TCH-10 Student Responses to Collaborative Strategies. R. G. JORDAN, Dept. of Physics, Florida Atlantic University, Boca Raton, FL 33431. In the Fall 1999, a new, two-semester, calculus-based course entitled "Physics for Engineers" was introduced at FAU. In developing this course I used some novel teaching strategies, such as in-class collaborative learning and an emphasis on conceptual understanding. In addition, I developed a large web-site that includes a number of features that supplement classroom sessions; examples include on-line practice quizzes, brain "busters" (i.e. a series of questions about everyday observations that test conceptual understanding) , and a discussion forum. I have monitored student opinion through mid-semester questionnaires and in my talk I will share the responses with you.

11:45 AM TCH-11 Using a Science Museum as a Resource for Homeschoolers. CHRISTIAN E. KOCH, South Florida Science Museum, 4801 Dreher Trail North, West Palm Beach, FL 33405. This presentation will show the growth of the Science Museum's programs over the past five years. The Museum's homeschool programs began in 1995 when it offered outreach programs to a small group of students several times throughout the year. In 1996, general science classes were taught on location to about 60 students in grades K through 5. With the success of the general science curriculum, a marine science section was added in 1997 with an additional attendance of 80 students. The program continued to grow in 1998 with the addition of an Astronomy series and a limited number of classes for secondary students. The secondary programs took off in 1999 with semester classes offered in Chemistry, Anatomy & Physiology, Marine Science and an Invertebrate and Vertebrate Dissection Series. This past year the secondary programs continued to grow with the addition of a second Chemistry series, Physics, Microbiology and a class on South Florida Ecosystems. There are presently more than 300 homeschool students that take classes at the museum each semester.

12:00 PM BUSINESS MEETING
RANDY CRISS, presiding

FRIDAY 2:30 PM LEWIS 307
SESSION B
RANDY CRISS, SAINT LEO UNIVERSITY, presiding

2:30 PM TCH-12 Educational Innovation in Science and Engineering : A Meeting of Knowledge in a "Team Setting". BJORN F. BACKMAN, Dept. of Civil and Environmental Engineering, University of South Florida, Tampa, FL 33620. This lecture presents an educational experiment in joining science and engineering to attempt to find a practical approach to prepare students for the "real world". Parallel to the required theoretical development in class, a "special project" was started to deal with applying acquired knowledge to practical engineering situations. Seven teams containing four-to-five members were formed by the students and a number of well defined tasks were assigned. Each team produced weekly presentations and reports. A final report was prepared for the end of the semester. The lecture addresses a number of interesting findings, discusses the results, and compares the results from two consecutive semesters. Several "surprising" conclusions are highlighted. The approach was designed as an extra credit activity. Feedback was given and opportunities to improve the depth of the team investigations were offered. The format seems to have stimulated much extra research into the special aspects of the weekly tasks, and at the end produced a great deal of thoughtful, good work.

2:45 PM TCH-13 Computerized Animation as a Component of Assessment. RICHARD PENDARVIS, Dept. of Science, Central Florida Community College, P.O. Box 1388, Ocala, FL 34478-1388. Animated GIF files were utilized in online testing of chemistry students at various levels via WebCT. The promise and perils of this methodology will be discussed. The need for change in assessment methods has ample precedent in the literature. Sheila Tobias states "In reviewing the literature of recent science education reform, one is struck by how much attention has been paid to pedagogy and content in college-level science, and how little the theory and practice of exam design, delivery, and grading have changed."(1) The methods we use for assessing our students and our teaching must change so that they no longer focus on the lowest levels of learning and so that they provide us with the insight into our methods and our tools that we need to drive change. Although the problems with computerized testing are well known, there are also some advantages. By incorporating animation into computerized testing, one can assess mental domains not easily open to us by ordinary means. One of the easiest ways of adding animation to computerized testing is through the use of animated GIF images. Faculty with little or no artistic or technical ability can create useful animations without expensive software. (1) Tobias, S. and Raphael, J. (1995), In-class Examinations in College Science-New Theory, New Practice. Journal of College Science Teahcing, v.24, no. 4, pp. 242-244.

3:00 PM TCH-14 Project ChemBOND: Innovations for Improving Student Performance and Retention in General Chemistry. J. E. HAKY (1), D. W. LOUDA (1), N. ROMANCE (2), C. E. CARRAHER (1), AND R. BLEICHER (2), (1) Department of Chemistry and Biochemistry and (2) College of Education, Florida Atlantic University, Boca Raton 33431. Many students nationwide perform poorly or withdraw from first semester General Chemistry, and often such students abandon science entirely. To address this problem, we have revised the course curriculum and instituted a 1-hour a week BONDing session (Building Opportunities for Networking and Discussion). During BONDing sessions, students work in small groups under the guidance of a student leader. The BONDing activities are designed to reinforce concepts introduced during lecture and utilize a wide range of learning techniques, including problem solving, flow charts, concept maps, model building, critical thinking, and discussion. Initial results over the past year indicate that student understanding and retention in the course have both improved significantly.

3:15 PM TCH-15 Project ChemBOND: BONDing Session Activities. D. CHAMELY, D. SNEDDEN, L. PARKER, D. W. LOUDA, AND J. E. HAKY, Department of Chemistry and Biochemistry, Florida Atlantic University, Boca Raton 33431. Part of our revision of General Chemistry involves an additional once-a week meeting with students, called a BONDing session. Student leaders provide guidance as a variety of activities are performed throughout the semester for the purpose of making basic concepts more understandable. Some of the specific activities are 1) and comparing it to the real periodic table so the students realize the principles of grouping elements with similar properties: 2) studying reactions, stoichiometry, and limiting reagents by building model airplanes out of various parts; and 3) creating a concept map to explore the relationships among acids, bases, electrolytes, dissociation, and neutralization. The details of these activities and their impact on student performance will be discussed.

3:30 PM TCH-16 Project ChemBOND: Integrated and Meaningful Laboratory Exercises in General Chemistry. D. W. LOUDA (1), J. E. HAKY (1), B. AUKSZI (1), C. E. CARRAHER (1), AND N. ROMANCE (2), (1) Department of Chemistry and Biochemistry and (2) College of Education, Florida Atlantic University, Boca Raton 33431. Ongoing revision of the first semester General Chemistry curriculum at FAU includes focusing on key concepts in lectures, incorporating BONDing sessions to reinforce these concepts, and altering lab exercises to coordinate with the other parts of the course. Laboratory experiments have been and continue to be altered to place more emphasis on understanding important ideas, including critical thinking and elements of the scientific method, and less on specific laboratory techniques. Individual experiments will be discussed, along with their integration into the overall course.

3:45 PM TCH-17 Some Historical Blunders in Chemistry. DEAN F. MARTIN, Institute for Environmental Studies, Dept. of Chemistry, University of South Florida, Tampa, FL 33620-5250. In preparing material for an upper-level exit course, "Historical Perspectives in Chemistry", several exciting discoveries, later found to be scientific blunders or hoaxes, were encountered. These include N-rays, Deryagin water, the magneto-optic effect (that led to the alleged discovery of Alabamine, "eka iodine"), the discovery of Illinium, and cold fusion. In reviewing some of these discoveries, at least three common features emerge: inadequate equipment, inadequate controls, and social pressures. Some blunders may have been hoaxes, but the more tragic ones were simply blunders made by well-meaning persons, who may well have been published in refereed journals. Ultimately, the true nature of the blunders emerged as a consequence of a wider peer review system that exists as a consequence of interest in exciting discoveries. The review of these blunders can provide good object lessons for our students and for ourselves.

4:00 PM TCH-18 Beneath City Streets: Public Archaeology on the Elementary Level. JILL CLAY, Department of Anthropology, University of South Florida, Tampa, FL 33620. Beneath City Streets was a project undertaken as a step towards enhancing archaeological awareness in elementary school students' education in the USF area. In order to forge responsible public attitudes toward stewardship of fragile heritage resources, public archaeology's maxim is that education is the vital first step. The proposal built upon an ongoing pilot program at the USF that entailed using archaeology educational kits and distributing posters into elementary schools within a tentatively identified service area of USF. Only one school was considered in the project in order to deliver an in depth presentation of archaeology as it relates to the immediate area surrounding the school, and the school's media specialist was consulted to ensure that materials were adapted to a fourth grade level, which was chosen because Florida History is taught at this level. Materials developed during the project (a presentation of the different archaeological time periods, suggested activities, resources, handouts, donated artifacts, photographs, a film, a newsletter, and maps) were placed into a box and housed in the school's media center for easy use by the instructors. A follow-up questionnaire was placed within the box in order to measure how serviceable the materials were to the school educators in their classroom instruction.

4:15 PM TCH-19 Study of Algal Aquaculture and Microbial Population Dynamics in an Inexpensive Lab Ecosystem. M. PAGE AND J.R. MONTAGUE, SNHS-Biology, Barry University 11300 NE 2nd Avenue, Miami Shores, FL 33161. A recent article in the *American Scientist* (S. Carlson, pp. 84-85, August 2000) outlined an inexpensive approach to algal aquaculture using sterilized, one-liter plastic bottles. We used this method to develop sterile cultures of the freshwater chrysophyte *Nannochloropsis japonica*, a golden-brown alga (inoculae obtained from *Aquaculture Supply, Inc.*, Dade City, Florida). *N. japonica* is related closely to diatoms but its cell wall lacks siliceous mineralization for most of the life-cycle. Two populations of *N. japonica* were initiated in November 2000 and monitored for 12 days. The qualitative results indicated the pattern expected for exponential population growth followed by population crash after a week. Microscopic examination suggested sterile conditions remained throughout the culture period. We recommend this system for demonstration of simple aquaculture techniques.

SOCIAL SCIENCE

FRIDAY 9:30 AM LEWIS 303
HUDSON REYNOLDS, SAINT LEO UNIVERSITY, presiding

9:30 AM SOC-1 Color Cues and Memory Recall. JENNIFER MOLBY AND RICHARD BRYAN, Saint Leo University. PO Box 6665, Saint Leo 33574. The purpose of this experiment was to see if the visual cue of color influences memory. There were 40 participants randomly assigned to four experimental groups based on color (white or yellow) of training and testing sheets. The participants memorized a list of 10 concrete and 10 abstract words and were given a recall test 24 hrs. later. Results indicated better memory for concrete than abstract words ($p < .05$) as predicted, but no effect of matching vs. mismatching of the training vs. test colors as had been hypothesized. There was, however, a marginally significant effect ($p = .06$) for the color of the testing sheet. This effect was stronger in abstract words; when the two groups of words were analyzed separately, this effect was statistically significant ($p < .05$) for the abstract words, but only appeared numerically for the concrete words.

9:45 AM SOC-2 Real World Application of Research on Forensic Interviews with Children. AMY L. WILSON, Saint Leo University, St. Leo 33574. Forensic interviews with children have recently been under investigation for the effects of interviewer techniques on the accuracy of testimony. Several conditions have high risk of contaminating a child's testimony. Little research has been conducted to determine what technique interviewers prefer using for children and whether it is consistent with research and published guidelines. Research has shown that some of the most informed professionals rely on traditional methods of evaluations, which may not be appropriate for children (Oberlander, 1995). This study surveyed 14 local interviewers' opinions and techniques for interviewing children. Eighteen open-ended questions were used to obtain a representation of preferences for certain techniques found to significantly effect reliability of testimony. Results will be discussed in terms of preferences and their reliability according to the research.

10:00 AM SOC-3 The Connection Between Cynicism, Neuroticism, and Conscientiousness. D. S. Moore, Saint Leo University, Psychology Dept., P.O. Box 6665, Saint Leo, 33574. It is known that those high in cynical hostility have greater troubles in dealing with people in general. The Scale of Interpersonal Cynicism (SIC, Moore, 1998) was created to measure the construct in terms of four areas: Cynicism Toward Human Nature; Cynicism Toward Relationship: Cynicism Toward Love;

Cynical Behavior Justification. The present study was designed to assess the degree to which high and low scores on the SIC subscales are associated with big-five personality dimensions. Neuroticism was more apparent for those high in CBJ and conscientiousness was less apparent. Only neuroticism was more apparent for those high in CTR. Only neuroticism was more apparent for those high in CTH. Neuroticism was more apparent for those high in CTL, and conscientiousness was less apparent, as was extraversion. These findings suggest that the cynic tends to be neurotic and vigilant in their dealings with others. They also may be more likely to use cynical attitudes to justify their negative behavior in terms of their relationships with others. The cynic may be less conscientious, more withdrawn and more vigilant in romantic relationships. Behaviors such as these have great self-fulfilling potential, and may affect the quantity and quality of satisfying interactions with others.

10:15AM SOC-4 The Effect of Parental Marital Conflict on Attachment Style and Romantic Beliefs. B.K.BRIGGS, Saint Leo University, St. Leo 33574. This study looked for correlations between the amount of marital conflict an individual experienced as a child and their attachment style and romantic beliefs as an adult. The three scales used were the Marital Conflict Scale, The Experiences in Close Relationships Questionnaire-Revised, and the Romantic Beliefs Scale. The correlation found between the Marital Conflict Scale and the Attachment Scale was significant (r (48) = 0.347, $p \geq 0.05$). In addition, this study looked for a correlation between experiencing a large amount of marital conflict and an individual's romantic beliefs. A negative correlation was found to be non-significant. Finally, the correlation between the attachment scale and the romantic beliefs scale was significant (r (48) = -0.294, $p \geq 0.05$. Thus, the results of this study show that there is a relationship between attachment style and romantic beliefs, as well as a relationship between the amount of parental marital conflict and attachment style.

10:30 AM BREAK

10:45 AM SOC-5 Perceptions of Alcohol University Norms For High-Risk Drinkers Involved With Informative Norm Feedback. H. A. FARRY, Saint Leo University, P.O. Box 6665, Saint Leo, 33574. Excessive drinking occurs at colleges and universities all over the United States and has been of concern for an extensive period of time. Heavy drinking is associated as a common risk among college students. Research reflects that ten to twenty-five percent of college students are heavy or problem drinkers, and a majority have misperceptions of the campus norms. The perceptions of alcohol use were investigated using a harm-reduction technique of informative feedback. It was predicted that high-risk drinkers (incoming freshman) would misperceive campus norms. Drinkers involved with the harm-reduction technique would have perceptions closer to the campus norms. A sample of incoming freshman students (N=60) were used from a private catholic university located in south central Florida. Participants were administered a questionnaire relevant to alcohol use and consumption which was used to attain alcohol perceptions. There were 38.3% males and 61.7% percent females with a mean age of 18.1 (sd=0.4). Results indicated that there were slight misperceptions of the norms among students and the harm-reduction feedback only showed marginal significance as an intervention technique.

11:00 AM SOC-6 A Comparison of the 2000 Presidential Elections in Mexico and Taiwan. JOHN J. McTAGUE, Saint Leo University, P.O. Box 6665, Saint Leo, 33574. Between March and July 2000, two of the longest reigning political parties of the twentieth century went down to defeat. In Mexico, the Institutional Revolutionary Party (PRI) had controlled national politics since its formations in 1929, while in Taiwan the Kuomintang (KMT), a party formed in mainland China by Sun Yat-sen during WWI, had dominated the island ever since Chiang Kai-shek had fled there with his supporters in 1949. Each party began to show weakness in the late 1980's, and their power continued to erode throughout the 1990s. But, it wasn't until the presidential elections of 2000 that each party suffered a disastrous defeat, in March in Taiwan and July in Mexico. This paper compares the political compares the political events in the two countries that led to these defeats, examining similarities and differences. It also attempts to foresee whether these setbacks are temporary or preludes to the demise of these two legendary political parties.

11:15 AM SOC-7 Date Rape: Attitudes and Knowledge of Young College Students, C. BERGER, N. MEIRA AND E.T. HAYS, SNHS, Barry University, Miami 33161. College women are very vulnerable to date rape but many college student are not very knowledgeable about it. ; Many believe rapes is an act of violence with little or no sexual connotation and a large percentage of rapes, particularly date rapes seems to go unreported. Thus the purpose of our study was to determine the attitudes and knowledge of date rape amongst a sample of undergraduate college students on the Barry campus. Twenty undergraduates male and twenty undergraduate females students between the ages of 18 and 21 were given a short nine question survey to complete. The average age for both groups was 19 years. No major differences were found in the responses between males and females. One small difference was the males underestimated by ten percent of women who knew their attackers.

A second difference was noted between males and females as to their knowledge of what percent of rapes are perpetrated on males. More disconcerting though was the fact that neither the male nor female students were very knowledgeable at all on this topic. This suggests the need for more education of young college students on date rape.

11:30 AM SOC–8 Social Nature and Everglades Restoration. WILLIAM E. O'BRIEN, Honors College-Florida Atlantic University, 5353 Parkside Dr., Jupiter 33458. Ecosystem restoration represents an important conceptual tool in sustainable development, exemplified in large-scale form in Everglades restoration planning. However, ecosystem restoration is debated among competing social science and humanities perspectives. This paper outlines critical perspectives on ecosystem restoration and argues for a "social nature" viewpoint that focuses on social relations and power, asking how nature in manipulated, by whom and for whom benefit, and with what social and ecological consequences. Discourse surrounding the Comprehensive Everglades Restoration Plan provides a case study of the social nature viewpoint as the Plan purports to reconcile the vastly divergent interests of environmentalists, developers, the sugar industry and other business interest, Native Americans, and officials at various levels of government. Such consideration of restoration informs contentions discussions over what counts as "nature" in public policy.

11:45 AM BUSINESS MEETING: SOCIAL SCIENCE
HUDSON REYNOLDS, presiding

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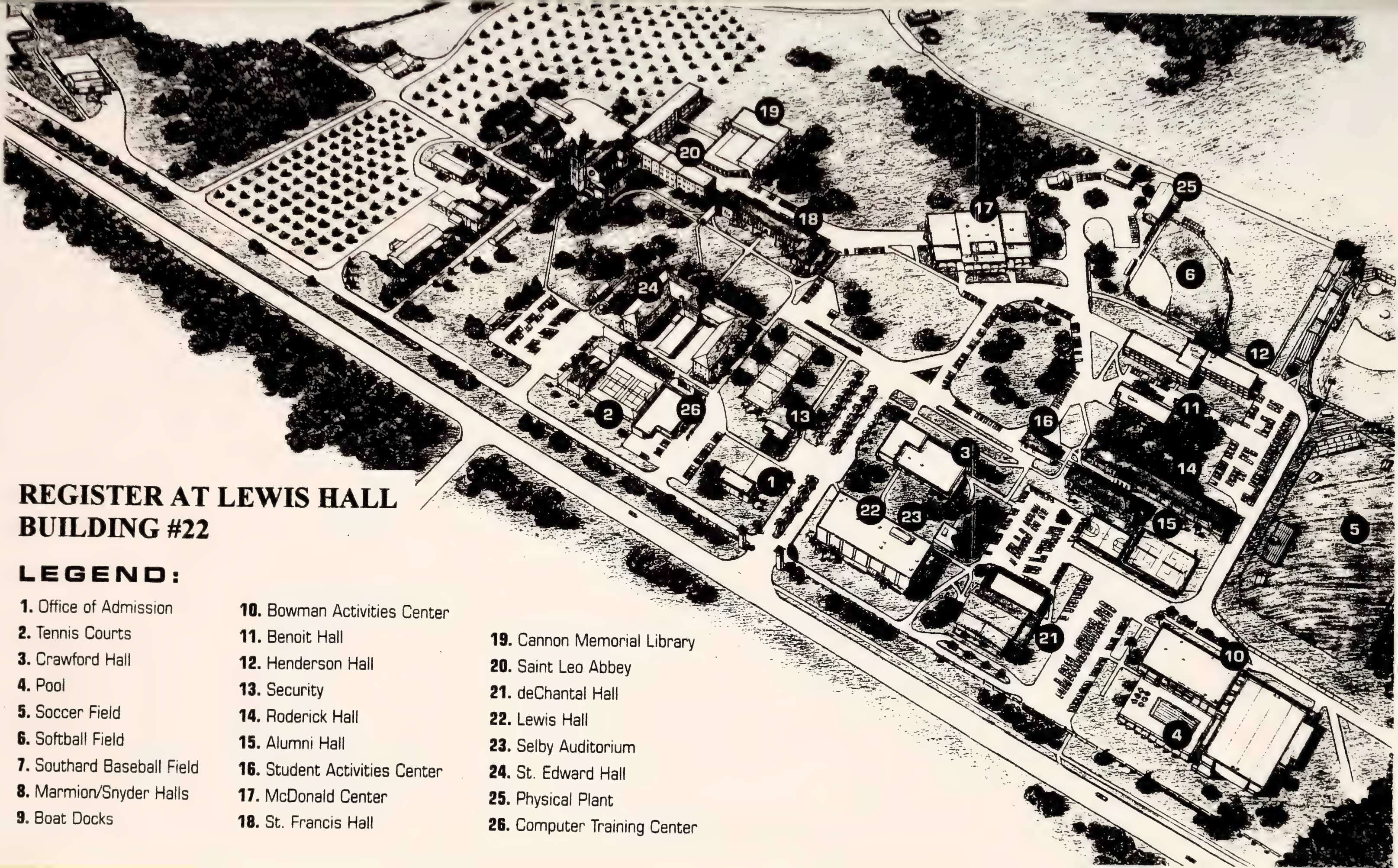

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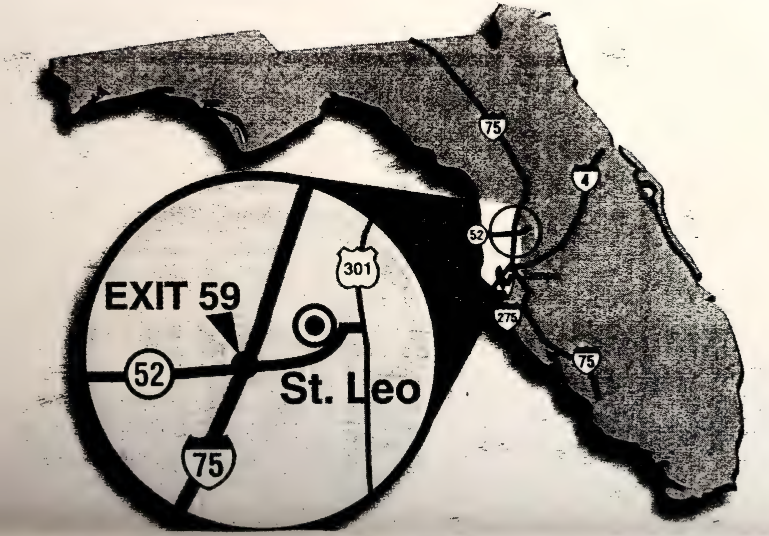

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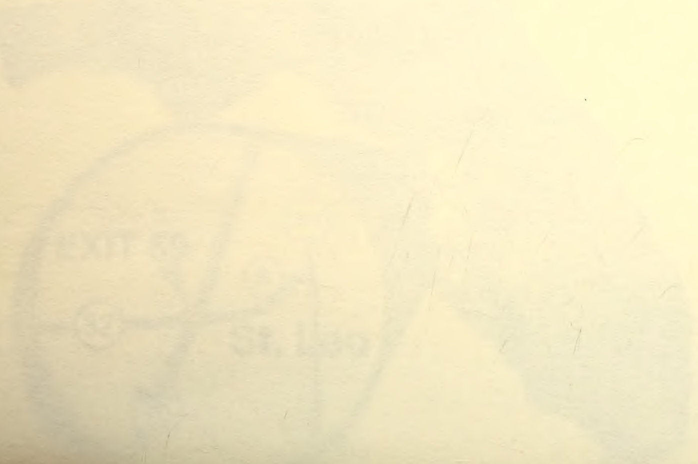

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